HUMAN AUDITORY INFORMATION PROCESSING

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A Thesis Submitted for the Degree of PhD
at the
University of St Andrews

1973

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Abstract

The purpose of this study is to investigate the flow of nonsymbolic auditory information in humans. To achieve this goal the observer adjusts the loudness of a Gaussian noise (GN) signal to match the perceived intensity of an electrodermal stimulus (EDS), a cross-modality matching task. The loudness of the GN and the voltage of the EDS were maintained within the observer's (O's) sensory probabilistic zone. The sensory probabilistic zone is a range of stimulus intensity from somewhere above "no detection" to "100% detection". The independent variable is a binary condition in that it consisted of catch trials 50% of the time and the remaining time of an EDS at <u>a</u> given intensity (previously determined at an intensity that elicited a response 50% of the time). Consequently, the O's adjustment of the GN reflected his decision-making processes, analysed by signal detection theory and cybernetics.

Experiment one demonstrated that neither practice nor the experimenter influenced the O's performance. Also, there are no residual carry-over effects. The O has difficulty assigning relative value to the auditory signals and has little or no difficulty in combining, organizing or co-ordinating the auditory information. The second experiment demonstrated that the O's difficulty in assigning relative value to the signals is due to a short memory retention of the nonsymbolic auditory signals (half-life of less than a second). However, verbal confidence ratings (VCRs) add persistency to the auditory memory (echoic memory), its half-life is extended to about 3.1 seconds. The VCR has a half-life of about four seconds. Experiment three demonstrated that nonsymbolic auditory information processing is not affected by interfering signals.

From a cybernetic model of the results it is concluded that nonsymbolic auditory information is processed by a filtered, single channel, series processor. Persistency is added to the system's memory component by an interaction between the auditory (echoic) memory and the conceptual symbolic system (VCR).

Preface

Declaration

The body of this thesis, Human Auditory Information Processing, has been composed by the candidate and the work recorded has also been done by the candidate. Neither the composition nor the recorded work has been accepted in any previous application for a higher degree.

Under Ordinance General No. 12 I was admitted as a research student in the Department of Psychology, University of St. Andrews, on November 1970 and as a candidate for the Degree of Doctor of Philosophy on 5 May 1971.

Certification

I certify that Ronald G. Hicks has completed eight terms of research work in the United College of St. Salvator and St. Leonard, University of St. Andrews, that he has fulfilled the conditions of Resolution No. 1 (1967) of the University Court, and that he is qualified to submit the accompanying thesis in application for the degree of Doctor of Philosophy.

....

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(Supervisor)

UNIVERSITY OF ST. ANDREWS

HUMAN AUDITORY INFORMATION PROCESSING

A THESIS SUBMITTED TO THE
FACULTY OF ARTS

IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
DEPARTMENT OF PSYCHOLOGY

BY

RONALD G. HICKS
ST. ANDREWS

DECEMBER, 1972.

ACKNOWLEDGEMENT

My deepest gratitude to the staff of the Psychology Department especially Professor M.A. Jeeves and Drs. D. Milner and F. Ledwith for allowing me to pursue my own interests while providing constructive feedback. Remembrance to Dr. Chester Darrow whose everyday example provided the motivation for this work and all future works.

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Chapter 1

Introduction

The purpose of this study is to investigate the flow of auditory information in the human being. This study could lead to the continued use of man as the supreme decision-maker by supplementing his deficiencies and harnessing his proficiencies. To achieve this goal, a simple auditory stimulus, unrelated to any previous learning, was varied with the aim of determining how human beings derive their decisions. The decisions were analyzed by probability theory. The subsequent knowledge of the synthesis of auditory information within the human being was then shown as a diagram. The rest of chapter one will expand and clarify this paragraph.

The term perception usually refers to the way one comes to know the world or the way one experiences the world of objects and events. The mechanism of perceiving has been of interest to man since his origin. Today every investigator has his own theoretical concept of perception.

Most investigators (Chaplin and Krawiec, 1968) accept four fundamental assumptions comprising (1) natural monism, (2) mechanism, (3) operationism, (4) determinism.

In this investigation the first three are adopted but for the fourth, determinism, Brunswik's (1950) theory of probabilistic functionalism is substituted. Brunswik's theory will be briefly described.

Probabilistic Functionalism

Brunswik (1955) based the concept of statistical uncertainty in the prediction of behaviour upon the assertion of a fundamental discrepancy between perception and behaviour. In the functionalist tradition, the theory stresses the achievement of the organism in adjusting to the environment and the processes involved. A percept is regarded as an inference about the world reached on the basis of cues from the environment. Brunswik felt that even if we could know everything about the stimulus conditions existing in the world and everything about the observer's responses, a perfect prediction about perception could still not be made. One can predict perception from behaviour or behaviour from perception with only a certain probability of correctness. It is, according to Brunswik, theoretically impossible to have strict laws of perception corresponding to Newtonian laws of physics.

The basic reason for the probabilistic character inherent in perception is that the observer is forced to reconstruct the external world on the basis of information reaching the sense organs. Bodily changes and changes in the environment prevent the reconstruction from ever being perfectly related to the objects in the environment. Thus the observer is perpetually in the process of making guesses or bets on the basis of uncertain information i.e., decision making.

Brunswik's probabilistic functionalism provides the philosophical framework for this investigation and topics such as statistical decision making, information processing, and cybernetics are compatible within this framework. "It is of utmost significance that in a number of specific instances cyberneticists have transgressed the limits of the machine boundary and have demonstrated the suitability of their conceptions in dealing with problems in which the spatial or temporal environment is made part of a larger system .... Communication theory may well contribute to the efforts to determine the structural and functional properties of the unit of behaviour in abstract terms. Such determination will in turn contribute toward an explicit recognition not only of the rules and restrictions but also of the licenses and liberties of the objective approach. It will further contribute to the much-needed establishment of psychology as a discipline of distinctive, well-circumscribed internal coherence and formal unity of purpose within the more broadly unitary framework of science at large (Brunswik, 1950, 87 and 92)."

Recently, Sjöberg (1971) in a review of Brunswik's probabilistic functionalism emphasised the application of probabilistic functionalism in perception, learning and applied psychology.

Information Processing

In attempting to explain man's behaviour, psychologists have not only generated their own particular theories but have searched in related disciplines for models that might be applied fruitfully in a behavioural context. Information processing converges from two main sources: (1) problem solving, and (2) physical communication sciences.

Until about fourteen years ago psychological research on problem solving was only sporadic. A few scientists worked consistently on the subject but there was no major point of view or technique to bring their work into focus. Then, Newell, Simon, and Shaw (1958) introduced a new theory of human problem solving, based on concepts of information processing and computer programming. They were primarily interested in the process of solving problems and argued that computer programmes could serve to specify unambiguous theories about the way humans process information. Information processing considers complex behaviour in terms of organizational hierarchies. Organized hierarchies of activities are the substance of computer programmes, so the language of programming, e.g., flow diagrams, subroutines, list structures and the like, provide a convenient way of talking about complex behaviour.

Physical communication science, communication theory, or, less accurately, information theory, provides a system for considering certain relationships between events which can be described in probabilistic terms. "Information theory" is used in at least three senses (Elias, 1970). In the narrowest of these senses, it denotes a class of problem concerning the generation, storage, transmission, and processing of information, in which a particular measure of information is used. The basic unit of informational measurement (the bit) has universal applicability and may be used wherever categories or classes of objects or events can be distinguished. In a broader sense, information theory can include any analysis of communications problems, including statistical problems of the detection of signals in the presence of noise, e.g., statistical decision theory. In a still broader sense, information theory is used as a synonym for the term "cybernetics" introduced by Wiener (1948) to denote, in addition to the areas listed in the foregoing, the theory of servomechanisms, the theory of automata, and the application of these and related disciplines to the study of communication, control and other kinds of behaviour in organisms and machines. Briefly, cybernetics means "steersman" and is concerned with the communication and variability of information and its use in controlling the behaviour of biological, physical and chemical systems. One of the first steps in a cybernetics problem, or programming an analogue or a digital computer, is the frequent use of diagrammatic representation of the system under study illustrating the relationships and interdependence of key system parameters. Such diagrams are often called information flow diagrams.

In summary, the role of information processing, or, more specifically cybernetics, has been related to complex behaviour. With this approach, man may be considered as a simple device for transmitting information; in a more complicated example, he may be considered as a component in a system that requires him to collect information, filter it, store it, evaluate it, and apply given rules to it, that is - man is a decision maker. The decision to utilize the cybernetic approach is one that I feel offers the greater flexibility in analysing the information reported in this paper.

Approach

The approach of this study is basically empirical. "The term empirical has to do with experience, but the word has at least two meanings which are commonly confused. The Germans make a convenient distinction between _Erlebnis_ and _Erfahrung_. _Erlebnis_ refers to present experience, that which is immediately there for the observer without reference to its origin; _Erfahrung_, to the accumulation of past _Erlebnisse_ (MacLeod, 1964, p.48)." This study will look at the data of _Erlebnis_. In this manner unnecessary assumptions as to how the human being is processing his information can be avoided.

Numerous studies have used verbal and visual information to develop hypothetical constructs concerning how humans process information. A hypothetical construct is an inferred concept, a conclusion derived from something assumed. Generally, a hypothetical construct has excess meaning (the semantic logic used to explain the observer's performance introduces ambiguity, e.g., stimulus recognition, memory storage and retrieval) and therefore the passage from the independent variables to the dependent variable is made with less than logical certainty (Bindra, 1959).

In experimental research in human information processing, there are several disadvantages inherent in the use of either alphabetical or numerical material as the stimulus. The main disadvantage is that the experimenter's interpretation of the dependent variable from the independent variable is made with less than logical certainty. This is because the observer must make the following transformation; (1) the recognition of a complex stimulus, (2) translating the stimulus into its basic components, (3) matching these components with data retained in memory, and (4) the storage and retrieval of complex sensory data to and from memory (Halle & Stevens, 1962; Katz & Fodor, 1963). Hence, the logical uncertainty between the independent and dependent variables is due to: (1) the observer performing complex tasks requiring numerous transformations, (2) each step in the sequence of transformations can introduce added probability of noise, and (3) as a result of one and two the conclusions concerning the observer's performance becomes increasingly ambiguous.

To determine how humans process information, why start with such complex learned stimuli? To eliminate as much excess meaning as possible from the transition between the independent variable and the dependent variable, this investigation required the observer to perform unique manipulations of simple sensory stimuli. Thus the observer's ability to process information can be described with greater logical certainty since there will be fewer transitions between the independent and dependent variables.

The reason for the investigation of Erlebnis is summarised by George (1970, p.25). "... it seems likely that we cannot wholly understand thinking and problem solving activity and the allied fields of learning, without having some knowledge of how information is received (as well as recognised and recalled) in the first place."

Cross-modality matching (CMM) means the degree of accuracy with which stimulus intensities can be matched across different sensory modalities (see Glossary, P.183). Cross-modality matching can be a useful tool in the analysis of human information processing behaviour. The advantages of using CMM are: (1) the sensory message transmitted to the observer is isolated from all other immediate sensory information; consequently, the message has no context - it is an entity, and (2) the sensory message does not have a past history - the message is unique. Also, if the observer's responses are analyzed according to statistical decision theory, the observer's response biases do not affect the data (Swets & Green, 1961). The data simply reflect the observer's ability to separate signal from noise on two sensory continua as determined by his ability to match the perceived magnitudes of the two signals.

In general, CMM seems to provide a useful laboratory tool for assessing how the observer processes information while eliminating many of the difficulties encountered with other techniques, typically problems involving: recognition, context, past history and response bias.

In summary, the proposed study is concerned with determining how the observer is processing auditory information. This can be accomplished by keeping the stimulus parameters constant and measuring the observer's consistency of responding as a function of the amount and kind of auditory information the observer has available. The flow diagram (Fig. 1) represents an oversimplified experimental design. The observer (O) is presented with the same stimulus condition (electrodermal stimuli, EDS) for the entire experiment. Likewise, the O performs the same task (CMM) of adjusting the magnitude of a Gaussian noise signal (GN) to match the perceived intensity of the ED stimulus (see Fig. 2). The only alterations in the experimental conditions are: (1) the O's access to auxiliary information about the GN is varied, and (2) the O may be required to perform an added response task of making verbal confidence ratings (VCRs) as to his certainty regarding the presences or absences of the EDS. By using this method some features of the information processing organisation of the auditory modality can be determined and also of its functional relationships to other cognitive structures.

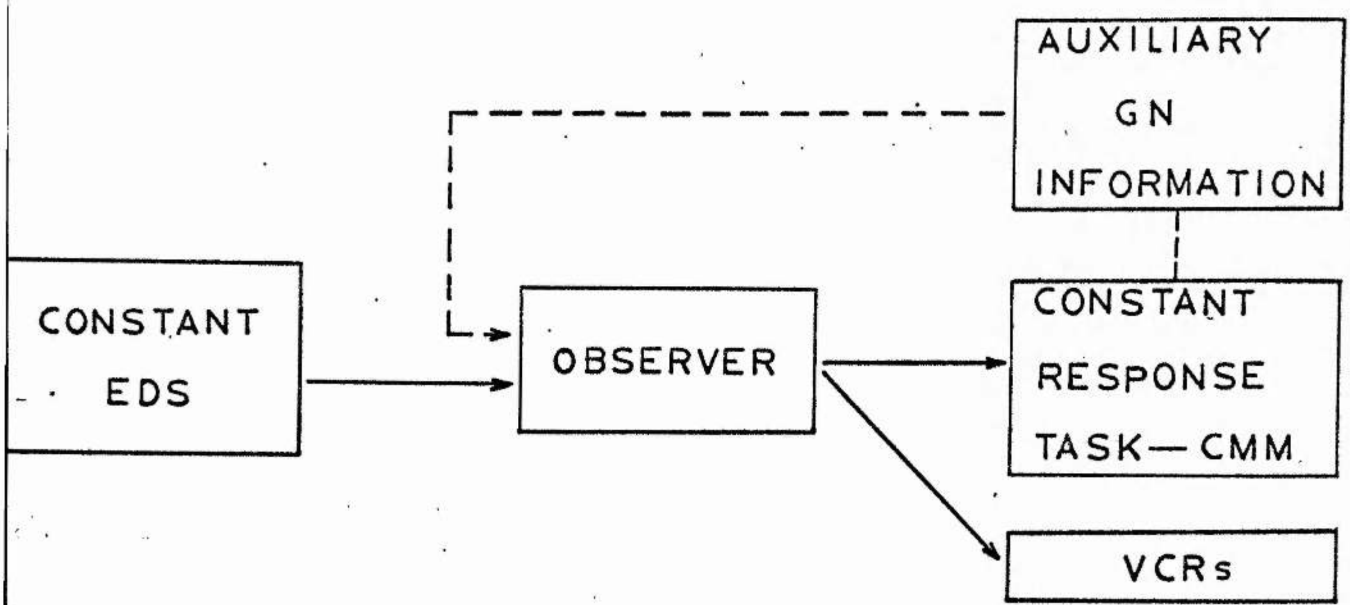


Fig. 1. - The flow diagram represents an oversimplified experimental design. The O is presented with the same stimulus condition (electrodermal, EDS) for the entire experiment. Likewise, the O responds with the same task (CMM) of adjusting the magnitude of the Gaussian noise (GN). The only alterations in the experimental conditions are:- (1) the O's access to auxiliary information about the GN is varied, and (2) the O may be required to perform an added response task of making verbal confidence ratings (VCRs) as to his certainty regarding the presences or absences of the EDS.

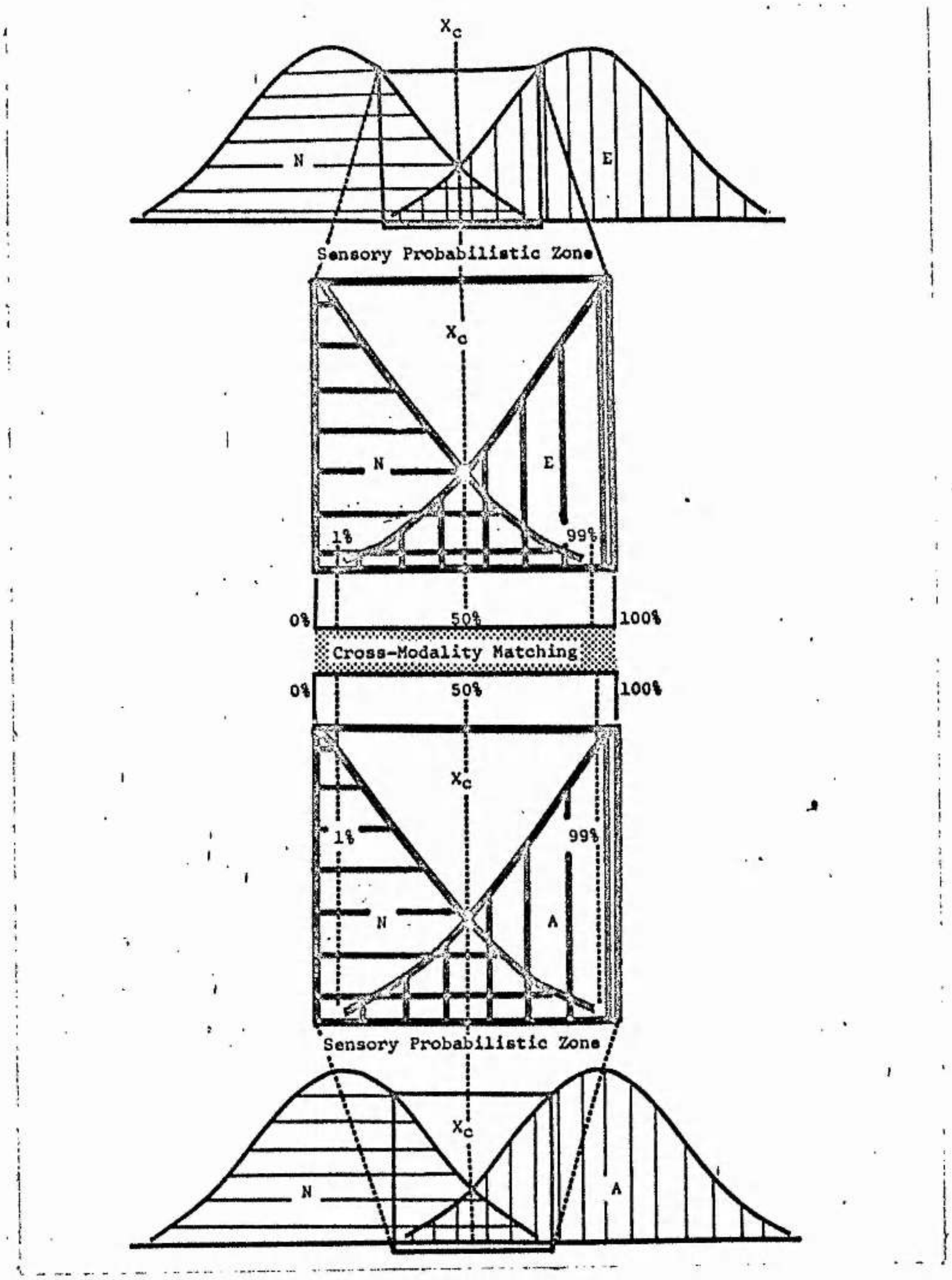


Fig. 2. - A theoretical diagram of cross-modality matching. The upper distributions show the electrodermal continua, the independent variable. The lower distributions show the auditory continua, the dependent variable. For the observer to maximize optimal separation of the signal from the noise with the least amount of errors, he should maintain his cutoff point at X_c. The observer's ability to maintain his response level at or around the cutoff point (X_c) on each trial is the experimental data.

Purpose

The purpose of this thesis is to investigate how human beings process auditory information. Based upon these investigations a cybernetic model will be developed. The model is applicable only to this investigation. Indeed cybernetic systems "must in a single human being, number hundreds of thousands (Porter, 1969, p.4)." No attempt will be made to fully develop a general theory; "... one should abandon the direct search for super theories of learning, super theories of development, and super theories of mental illness or perception. These have proved themselves to offer a redescription rather than an explanation, which is the danger into which psychologists, like us all, are particularly prone to fall (Scriven, 1964, p.176)." However, a modality specific model (audition) will be developed that encompasses the experimental results reported here and related findings of other studies.

Chapter 2

Selective Review of the Literature

This chapter selectively reviews the literature in three areas that provide the theoretical foundation for this study: (1) cross-modality matching, (2) cutaneous information, and (3) information processing of simple auditory information.

Cross-Modality Matching

Cross-modality matching (CMM) has been previously defined (p. 9) as the degree of accuracy with which a sensory intensity can be matched across modalities. The purpose of this study is to determine the flow of auditory information (Erlebnis) within the organism. The purpose is achieved by having Os perform a CMM task and then observing how the O's performance alters when auxiliary information about the auditory signal is provided. For the present study only one aspect of the flow diagram is of direct interest - audition. Even though the Os do match a signal intensity across modalities it is the Os' accessibility to auxiliary auditory information that is changed. Consequently it is of indirect importance how the Os transfer information from one sense to another; or how cross-modality contextual and assimilation effects influence the O's judgments; or how the presence of a sensory stimulus in one modality facilitates the detection of a signal presented to another modality. However the above topics are of some importance since the Os do match sensory intensity across modalities.

Cross-modal integration is a wide and heterogeneous field of study. Most of the topics reviewed have been limited to studies that have used auditory stimuli. There is not a discrete separation between topics, although the categories are helpful in the organization and communication of the material. The review topics are: (1) sensory transfer, (2) contextual and assimilation effects, (3) facilitation, (4) equivalence, and (5) psychophysical measurement.

Sensory Transfer

Two types of sensory transfer can be defined: intersensory or cross-modal transfer occurs when an organism uses information from one sense modality to perform a task or solve a problem involving a different sense modality; intrasensory, or intramodal, transfer occurs when both the information and the task are in the same sense mode.

Eleanor J. Gibson's book Principles of Perceptual Learning and Development, chapter eleven, provides an excellent historical perspective of intermodal transfer research as well as a review of work up to about 1968. Recent reviews on studies in cross-modal transfer (e.g. Bjorkman, 1971, and von Wright, 1970) emphasise the following findings: (1) cross-modal transfer is easily demonstrated with human beings but CMM is extremely difficult and perhaps impossible in animals, (2) the capacity of cross-modal transfer seems to be a function of age, and (3) the transfer effect is often found to be asymmetric (e.g. information transfer from touch to vision is larger than transfer from vision to touch).

In explaining the third empirical finding, from the above list, several authors have suggested that verbal mediation may play an important role in cross-modal transfer (see Garvill and Molander, 1968 for a review of verbal mediation effects in cross-modal transfer). However, it is also argued (Garvill and Molander, 1971) that not all forms of cross-modal transfer need to be mediated by language or verbal behaviour (Blank et al. 1968). Blank et al. trained young children in a form discrimination task either visually or tactually and tested for transfer in the other modality. They obtained transfer from vision to touch but not in the other direction. Although transfer occurred, the children could not label the shapes used and the authors concluded that language was not a necessary mediator for transfer.

The soundness of this conclusion can be questioned, however, since no transfer occurred from touch to vision and since the lack of overt verbal responses by no means excludes the possibility of covert verbal responses.

Garvill and Molander (1971) trained Os to associate nonsense syllables to three-dimensional ceramic objects (Gibson's forms, 1966) which were presented either visually or tactually. Verbal mediation was found to be an effective aid in the transfer of information between the two sensory modalities.

Previous studies of cross-modal matching between vision and hearing used some version or modification of the Birch and Belmont test (1964). It is an audio-visual "matching to sample" task in which the O listens to a pattern being tapped out, then selects from among three or four Morse-code-like patterns pictured on a card the one which corresponds to what he heard. The differences obtained between groups on audiovisual matching ability, using this test, may be affected by three other types of performance implicit in the test structure: (1) spatiotemporal transformation - a temporal auditory pattern is compared to spatial visual patterns; (2) counting - in some items the comparison patterns do not all contain the same number of elements; (3) length perception - in other items the visual comparison patterns do not have the same length. These performances might not differ as much in normal adults as they do among the groups that Birch and Belmont tested, which mostly consisted of children or of persons with brain damage.

These earlier studies, while evaluating audio-visual transfer, did not report on either the complementary cross-modal performance, viz. visuoauditory transfer, or intramodal transfer for both vision and hearing. The inferiority of cross-modal transfer reported by Birch and Lefford (1963) can be due to comparing it to the intramodal transfer within the most accurate of the two sense modes in question; on the other hand, comparing cross-modal transfer to the intramodal transfer within the less accurate of the two senses should result in cross-modal superior performance (Bryant, 1968). Muehl and Kremenak (1966) introduced the necessary intramodal comparisons by adding the complementary visuoauditory CMM task, and changed the test from "matching to sample" to "same-different". Their items, however, were different among the four tasks, and differences in item difficulty could have affected the differences obtained among their conditions; also, their cross-modal tests still involved spatiotemporal comparisons from vision to hearing, while the intramodal tests for vision and hearing involved only spatial and temporal comparisons, respectively.

Rubinstein and Gruenberg (1971) compared cross-modal matching between vision and hearing to intramodal matching within these modes in normal adults. Temporal pattern perception for vision and audition was measured using pair comparisons of precisely determined rhythms as test items. Visual rhythms were more difficult to match than were comparable auditory ones. The differences between intra and cross-modal transfer were related to the frequency of pattern elements, with cross-modal performance decreasing more when frequency rose.

Chan and Travers (1965) studied the effects of sense modality switching on the learning of elements in a serial learning task. The study involved a task with seven nonsense syllables, each of which could be presented in either the auditory or visual modality. Switching the sense modality of transmission took place with some Os on the second position and with other Os on the fifth position. At the higher of the two speeds of presentation used, there was no significant effect on learning produced by switching modality in the second position. However, the switching of modality in the fifth position produced: (1) a significant increase in learning the syllable on which the switch occurred, and (2) a significant decrement in learning of the following syllable (the sixth position), which involved a switch back to the original modality. The increment was interpreted as a von Restoff effect, and the decrement was considered to be a result of loss of time involved in switching (see Reid, 1964, for a review and his added studies on time loss caused by switching modalities).

The fact that in the Chan and Travers (1965) study the effect of switching was much more marked in the fifth position than in the second suggests that, as information is received through a particular sense modality, switching to another modality requires an increasing amount of lost time. Their 1970 study investigates further this tendency for switching effects to become more marked as a particular sense modality continues to be used for information transmission. This study used as signals either brief series of flashes of light or brief series of sound "blips." Each signal consisted of 3, 4, 5 or 6 flashes or blips. Four signals were given consecutively through either the auditory or the visual modality. The task of the O was to report at the end of each series of four signals the number of flashes or blips in each of the signals. The design of the study involved a switch in sense modality at each one of the four possible positions in the series. Thus, it was possible to determine if the transmission of information through one sense modality makes it progressively more difficult or more time consuming to switch to another source of information transmitted through another modality. The results generally supported the contention that, as information is received through a particular modality, there is a build-up of the disruption involved in switching sense modality.

In conclusion, sensory transfer does occur asymmetrically and is influenced by verbal mediation effects. Also, switching sense modalities disrupts information processing.

Contextual and Assimilation Effects

Anchoring or contextual effects in psychophysical judgments may take the form of either contrast effects or assimilation effects. (An anchor is a reference point in the O's stimulus or response continuum set at some mathematically defined intensity by the experimenter.) A contrast effect occurs when the presentation of an anchor produces a shift in the judgment of control stimuli toward that portion of the judgment scale most distant from that used for judging the anchor. An assimilation effect occurs when the effect of the anchor is to move the judgments of the control stimuli toward the portion of scale used in judging the anchor.

The theory of adaptation level (Helson, 1964) offers a rather parsimonious explanation of contextual effects. This theory presupposes that scaled psychophysical judgments represent the distance of the stimulus from a point of sensory indifference (the adaptation level), based upon the O's experience with the focal stimuli, background stimuli, and residual stimuli from his previous contact with the stimulus domain. The effect of presenting an anchor is to shift the adaptation level toward the anchor. As the distance between the original set of stimuli and the adaptation level has changed, and the scale judgments are proportional to distance from the adaptation level, the judgments of these stimuli will shift toward the end of the scale opposite the anchor. Thus, comparatively high intensity anchors decrease the judgments of scaled stimuli and comparatively low intensity anchors increase them.

A difficulty with the adaptation-level analysis of context effects is that only contrast effects are predicted. (Here, the relevant item of adaptation-level theory is that all background stimuli as well as the test stimuli are pooled in the O's decision). On the other hand, Sherif, Taub, and Hoyland (1958) were able to obtain assimilation effects in the judgment of lifted weights when the anchoring stimulus was close to the series stimuli in value. Parducci and Marshall (1962), however, offered an explanation of this phenomenon congruent with adaptation-level theory. Rather than considering the anchor as simply one of the stimuli to be judged and finding the adaptation-level as the assimilated effect of independent stimuli as did Sherif et al, the anchor was considered by Parducci and Marshall to be a standard in regard to which each comparison stimulus was evaluated. Consequently, values for the adaptation level were obtained such that Sherif's results were predictable as a contrast effect and therefore congruent with adaptation-level theory.

The difficulties in considering assimilation as an adaptation-level effect have been increased by the demonstration that assimilation effects may be obtained in cross-modal judgments. Bevan and Pritchard (1964) obtained a typical contrast effect in the judgment of soft tones when more intense tones were introduced as anchoring stimuli. However, the introduction of lights, previously matched in intensity to the loud tones, produced an assimilation effect in the judgment of the soft tones. They were judged louder in this condition than in a soft tone control condition.

In order to incorporate the assimilation effect into adaptation-level theory, Bevan and Pritchard interpret the anchor effect as a "paradoxical anchor effect." They reasoned that cross-modal anchors are less potent than anchors within the same modality as the series stimuli. A less potent cross-modal anchor may be equivalent to selecting an anchor of lesser magnitude within the same modality. If the visual anchor is very low in potency, it may be equivalent to a tonal anchor below the series of tones presented for judgment. This would produce a contrast effect and increase the apparent magnitude of the soft series of tones. The experimental results of Bevan and Pritchard confirmed their postulate.

In order to support the conclusion that the cross-modality assimilation effect is a sensory effect congruent with adaptation-level (AL) principles, three factors of the Bevan and Pritchard study should be resolved: (1) effects of attention shift between tone-light conditions as opposed to the tone-tone conditions, (2) role of response biases, and (3) the role of verbal mediation.

Melamed's(1970 and 1971) studies were designed to investigate the contribution of the verbal mediation factors to cross-modality assimilation effect. In summary, the O's verbal judgments of intensity of soft tones judged with a series of bright lights (assimilation effect) werefound to be dependent on the fact that the lights were judged at the same time. The dependence between tones and lights was not observed in a parallel investigation of contrast effects in the judgments of tones alone. "Both the form of the assimilation effect and its specific dependence on judging both stimulus modalities argues against a sensory explanation. Instead, it is argued that this cross-modality assimilation effect represents a resolution of the specific difficulties involved in judging two qualitatively different modalities on one judgment scale (Melamed, 1970, p.185)."

Namba, Yoshikawa and Yasuda (1972) investigated anchor effects on loudness judgments, using reaction time (RT) as an index of loudness. Their problem, of equal concern to all who study perception, is that perception is an unobservable intervening concept. We can only guess the perceptual world from relations between stimuli presented to Os and the overt responses made by Os to the stimuli. Therefore, it is only possible to use responses as a clue to the law of perception. Consequently, the characteristics of responses might be confused with those of perception, and sometimes it happens that what was considered as the law of perception is found to be nothing but the law of response, e.g. Stevens vs. Helson's extending AL theory to a category judgment of weight (Stevens, 1958).

In order to eliminate performance deficiencies accompanying verbal categories, there have been many experiments concerning anchor effects using absolute physical magnitude. For example, Fillenbaum (1963) used a verbal category scale and a direct ratio of height to the width of rectangles and found that the O's judgments reflected no anchor effects when direct ratios were used.

Harvey and Campbell (1963) found anchor effects in the judgment of weight using a verbal category scale and physical magnitude (ounce), but in the latter case the effects were smaller. Helson and Kozaki (1968) showed that the same anchor effects existed in direct estimation of the number of dots, as when a category scale was used. Bell and Bevan (1968) found clear anchor effects in the judgment of four factors of Gestalt. Besides, anchor effects have also been seen in many experiments where stimuli of low intensity were used as anchors (Black and Bevan, 1960; Goldstone et al, 1962; Bevan and Pritchard, 1963).

As described above, many experiments have been done in order to make clear the relation between perception and response concerning anchor effects. Though many of these authors deny that anchor effects are attributable merely to the semantic shift of scaling, there is no general agreement as to the exact nature of anchor effects.

In order to reexamine the problem of verbal mediation influencing anchor effect, Namba and et al (1972) conducted two experiments. In Experiment 1, anchor effects were reexamined using verbal categories. Two kinds of auditory anchor stimuli, 60 and 90 dB at 1,000 Hz, and four kinds of series stimuli, 60, 70, 80 and 90 dB tones, were used. In this experiment, clear anchor effects were found as in previous experiments. Experiment 2 was conducted using reaction time (RT) as an index of loudness with stimulus conditions similar to those in Experiment 1. The same anchor effects could also be demonstrated in this experiment.

As RT is quite free from the limitations inevitably accompanying the verbal responses, it was concluded that the anchor effects reflect the shift in perception and are not caused by verbal mediation effects.

In summary, anchor effects probably reflect a shift in perception and are not caused by verbal mediation. Secondly, cross-modality assimilation effects probably represent the O's difficulties in judging two qualitatively different modalities on one judgment scale.

Facilitation

Here, facilitation means the increased ease of detecting the presence or magnitude of sensory stimuli in one modality by introducing a sensory stimulus to another modality. However, studies of the effects of auxiliary visual stimulation on absolute auditory sensitivity have not totally agreed on their results. Most studies have shown that auxiliary white light improves auditory sensitivity (reviewed by Özbayder, 1961). However, Sheridan et al (1966) reported that white light had no effect on auditory sensitivity at four frequencies examined (250-2000 Hz), but depressed sensitivity at a fifth frequency (6000 Hz). Other investigators have found that concomitant stimulation with certain coloured lights can depress auditory sensitivity (London, 1954 reviews this subject). In none of the above mentioned studies, however, was there evidence of any attempt to control or measure false positive responses.

Bothe and Marks (1970) attempted to evaluate the effects of white light on the detection of Gaussian noise. The conditions compared were darkness, constant room illumination, and sound-synchronized flashes of light at three intensities. Use of a confidence rating procedure and analysis in terms of the theory of signal detectability provided an opportunity to separate any effect of auxiliary visual stimulation on auditory sensitivity from an effect on criterion. This could be accomplished by comparing the entire receiver-operating-characteristics for all of the conditions. The authors concluded that there appeared to be no consistent effect of auxiliary visual stimulation on absolute auditory sensitivity for the four Os examined.

In conclusion, the previous studies have appeared to incorporate the O's response biases into his detection accuracy resulting in a lack of experimental reliability. The Bothe and Marks (1970) study, which removed response biases from the O's detection accuracy, has not confirmed that facilitation has any influence upon the O's ability to detect stimuli.

Equivalence

Here, equivalence means that the information gathered by one perceptual system is "covariant, coincident, or correlated with the information got by another perceptual system (Gibson, 1966, p.298)," and thereby "unity" is achieved. In general the studies in this section are concerned with how "unity" is established.

J. Gibson (1962) reported use of a series of sculptured free-form solid objects designed especially to be appropriate for the study of haptic (active touch) perception. Each object has a solid three-dimensional shape with five elevations around a central hump. The exact shapes and sizes of the elevated protuberances, as well as the valleys and ridges among them, distinguish each solid from the others in the series. Abravarel (1971) used these objects for investigating haptic and visual equivalence matching, as well as for the study of short-term memory demands on mnemonic processes as well as perceptual ones. Five groups of Os were tested under conditions of intra and intermodal equivalence matching for free-form unfamiliar shapes. Gibson's (1966) findings indicated that visual intramodal matching was superior to intermodal matching, a result consistent with his previous research (Gibson, 1962). The order of accuracy in forming equivalence was: (1) intramodal visual, (2) intramodal haptic, (3) haptic to visual, (4) visual to haptic.

Numerous other CMM studies have established the greater detection accuracy of the visual to tactual comparison over the tactual to visual comparison (Garvill and Molander, 1969; Lobb, 1970; Koen, 1971). Goodnow (1970) proposed that the difficulty of the visual-tactual condition relative to the tactual-visual condition could be explained in terms of a less stable memory for tactual information. This hypothesis was based on results obtained by Posner (1967), who compared retention of kinesthetic and visual information and found that the retention of kinesthetic information was affected by an unfilled retention interval while the visual information was not. Goodnow (1970) found that the difference in difficulty between: visual standard and visual comparison; tactual standard and tactual comparison; visual standard and tactual comparison; and tactual standard and visual comparison, increased as a function of the number of comparison objects, which supported her hypothesis.

However, Garvill and Molander (1972) did not confirm Goodnow's hypothesis. They manipulated intra and cross-modal matching of nonsense forms (Gibson's forms) using two standard modalities (visual vs. tactual), and two comparison (again visual vs. tactual). The standard form was separated by either one, ten or thirty seconds from the comparison. The authors conclude that retention intervals had no effect in any of the modality conditions. There are two faults with this study. Firstly, the Os' criterion biases were incorporated in the data. Secondly, the Os could easily verbally code the forms, consequently, a retention interval between the standard and comparison would not have an effect since the information could be stored in the verbal memory for all possible combinations of forms.

When a perceptual problem can be solved by exploring the stimulus objects visually or tactually, or when part of the problem is presented via one modality and the remainder via another modality, there is an opportunity to compare the information-handling characteristics of the two systems. In a situation employing multivariant stimuli, some properties may be more salient for one modality than for the other, resulting in differential problem difficulty for the two modalities.

While Gibson (1962) has demonstrated that tactual-to-visual matches can be made without previous experience, although performance improves with practice, most studies have been concerned with form discrimination and subsequent cross-modal transfer of training (see section on sensory transfer). The difficulty in interpreting and integrating the results of cross-modal studies seems to arise because there is no basis for determining why equivalence does or does not occur. Except for Pick (1965), the studies have suffered from a lack of stimulus quantification and little is known about the form dimensions along which discrimination, matching, and cross-modal transfer takes place. Psychophysical knowledge of what stimulus information is used and how it is used in transfer or cross-modal comparison should aid in understanding the processes involved.

In earlier studies, a comparison of the physical correlates of visual and tactual form complexity scales (Owen and Brown, 1970) demonstrated a high degree of equivalence in information utilization. Other studies verified these findings using multidimensional scaling analyses (Brown and Brumaghim, 1968) and an anchoring design (Brumaghim and Brown, 1968). Owen and Brown (1970 and 1970) investigated pattern discrimination in the case of visual and tactual presentations. The tactual stimuli were forms constructed of fine abrasive paper glued onto a poster board. The visual stimuli were transparencies presented with the same area as the tactual forms. The O's task was to match one of six randomly presented forms to the test form. The data were analysed by correlating both intra and intersensory comparisons. There was no attempt to separate the O's criterion for responding from their sensitivity of detecting the forms. The authors concluded "if task demands or previous problems do not suggest a strategy, the information in the problem will (p.306)."

Anderson (1965) studied the relationships between visual and auditory autokinetic phenomena and affirmed that these phenomena are indeed determined by each subject's perceptual style. Gunn and Loeb (1967), using signal detection theory, determined a correlation between auditory and visual tasks. They concluded that both sensitivity (d') and the degree of conservation in responding (β) were correlated between the two tasks. Both d' and β for auditory and visual tasks were significantly correlated in the first session. Only d' was significantly correlated in the second session. The authors contend that there are common response biases in different modalities which are independent from common factors affecting sensitivity (d') for both modalities, auditory and visual.

An unusual study on intermodal equivalence was conducted by Bruno et al (1971) on the cross-modality matching of muscular tension to loudness. The purpose of this study was: (1) to determine, more precisely, the relationship of perceived tension to the magnitude of sustained muscular contractions, as measured electromyographically, and (2) to validate these findings through cross-modality matching of tension to loudness. The study involved individual tension, loudness, and matching functions, each taken in the same session. In a single session, Os produced and estimated a series of electromyographically measured tensions, estimated the loudness of pure tones, and then matched muscular tension to tonal loudness. In all cases, power functions adequately represented the estimation and matching data. The data suggest that a consistent scale of muscular tension can be constructed, and that the scale can be validated by cross-modal comparison.

In another single experiment by Dawson and Brinker (1971), Os adjusted loudness and force of handgrip to match the strength of their opinions regarding racism, desirability of occupations and pronunciability of trigrams. The results, by the authors' contention, "provide validation of ratio scales of opinion and further establish the direct scaling methods used to obtain them (p.413)."

Psychophysical Measurement

In 1967, Egan published a bibliography on Signal Detection Theory and Psychophysics. Sections of the bibliography include: (1) decision processes in detection, (2) theoretical analysis of SDT, and (3) sensory processes in auditory detection and its theoretical analysis. The entire bibliography contains a minimum of a thousand references. Clearly a review of this work is beyond the scope of this paper. An excellent contemporary review of psychophysics is provided by Luce (1972).

Rule and Markley (1971) summarise Steven's power function to cross-modality matching of individual differences. Also Banks (1970) and Lockhart and Murdoch (1970) provide a basic introduction to signal detection theory and its practical utilization.

Cutaneous

There are four physiological functions of the human skin: (1) protection of underlying parts, (2) regulation of body temperature, (3) participation in body metabolism, and (4) operation as a sense organ. The skin is richly endowed with nerves and their end organs; it has a surface area of approximately two square yards in the average male and comprises 16 to 18 per cent of the body weight. Historically, however, the systematic investigation of the cutaneous sense has been curiously neglected.

Early work in the area of reading by touch was first done by Braille in 1826 in which he developed the well-known Braille system. The method has proven to be relatively efficient, but it is slow and efficiency is substantially reduced by perspiration and cold fingers. Also, the maximum speed of reading is less than the cognitive processing time required. In 1938 Gault and his associates unsuccessfully attempted to utilize the skin as a tympanic membrane by transducing speech sounds into mechanical vibrations and applying them directly to the skin. Weiner and associates (1951) used alternating current applied to the skin through a filter network of seven channels, but found this system not very efficient for communication purposes.

The earliest successful attempt to utilize the skin as a modality of communication was made by Geldard in 1957. Using a coded "vibratese" language developed by Howell a year earlier, and transmitting through seven mechanical vibrators critically spaced around the chest, Geldard was able to get his subjects to receive messages at a rate of 38 words per minute with better than 90 per cent accuracy after 30 hours of training. Words averaged five letters in length and the method proved several times faster than the conventional Morse Code.

Probably more important than the study itself were the data he obtained on certain aspects of vibratory stimulation such as: (1) amplitude-intensity, (2) position of stimulation, (3) duration, and (4) frequency. Geldard's results are discussed:

Intensity Discrimination

Geldard found that at 60 Hzs with a static vibrator pressure of 100 grams, the useful range of stimulus amplitude was between 50 and 400 microns, 50 microns was above the 100 per cent absolute threshold of sensation and 400 microns was well below the threshold of discomfort. Within this range fifteen just-noticeable-differences

(JNDs) could be discriminated. Three widely spaced steps of low, medium and high intensity could be used in communication. Some problems encountered were those of adaptation to vibration, variation in sensitivity to touch in different areas of the body, and maintenance of a steady stimulus from the vibrators.

Position of Stimulation/Locus

A number of problems arise in the use of mechanical vibrators for communication. One such difficulty is the bulky nature of the vibrators themselves and the wattage necessary to drive them for adequate stimulation. However, by using a small low-powered vibrator developed by Bice that operated on low frequencies and could not be dampened by skin impedances, Geldard was able to space seven vibrators on the rib cage with 100 per cent identification of the site of stimulation. Five vibrators proved to be sufficient for a communication system. However, if any two vibrators were simultaneously activated they were felt as one. Also, when the vibratory patterns started simultaneously and had the same intensity and frequency, the patterns could not be discriminated. This problem could be overcome by a split-second temporal differentiation between two series of vibrations from separate vibrators, which restored "twoness" but could, in turn, lead to problems in coding and the phenomenon of "phi movement". Another problem was that of the "spread" of vibratory sensations around the general locus of the vibrator which was overcome by a method devised by von Békésy (1962).

Stimulus duration

At a frequency of 60 Hzs, Geldard found 25 JNDs between the range of 0.1 seconds and 2.0 seconds in stimulus duration. Below 0.1 seconds vibratory bursts were too short to be discriminated, while signals lasting longer than 2.0 seconds were too time-consuming for communication purposes. The mathematical function was slightly curvilinear, the shortest stimulus duration perceived was 0.15 seconds. Absolute identification of duration for trained observers yielded four or five widely spaced levels, and only three levels for untrained observers. Three durations yielding 100 per cent accuracy of discrimination were used for Geldard's basic system. These steps were 0.1 seconds, 0.3 seconds, and 0.5 seconds which lie about 4 JNDs apart.

Frequency

This was found to vary inversely with the number of correct judgments. At frequencies below 70 Hzs judgments were good but faded as frequency increased. Therefore, Geldard decided that frequency must be constant in the communication system.

The basic system that arose from the results of the foregoing data consisted of three levels of intensity, three durations, and five loci. This gave Geldard a forty-five element system of tactile communication to be used with Howell's coded "vibratese" language. White, (1970), using Geldard's findings, examined the potentialities of the skin as a communication channel using vibrotactile stimuli. A system was developed for converting an optical image into a tactile display. After surprisingly little training, subjects were able to recognise common objects and to describe their arrangement in three-dimensional space. When given control of the television camera used for the experiment, subjects quickly achieved object discrimination. White concludes that the limitations of the system thus far appear to be more a function of display resolution than limitations of the skin as a receptor surface. Some contemporary investigators believe that electro-pulse stimulation might provide the necessary resolution.

In 1953 Siegal demonstrated that within certain parameters electrical square wave pulses, on the upper volar forearm, result in pain-free perceptions of touch. The advantage of using electro-pulse stimulation is that it can be confined to a particular skin area unlike stimulation by mechanical vibration. Electro-pulse equipment is more compact and requires less than 1 watt of power for stimulation. The disadvantage is that electrical stimulation can produce pain under certain conditions.

In 1958 Hahn elaborated on Siegal's method by using a high impedance source and varied the frequency and duration of a square wave. Voltage was held constant. Although sensation was found to be affected by frequency change, current increase, and cycle duration, Hahn's method enabled him to study each variable separately. Using the index finger as the locus, frequencies of 60, 100, 200, 500 and 1,000 Hzs and short durations of 0.1, 0.2, 0.4, 0.7, 1.0, 2.0, 4.0, and 7.0 milliseconds, Hahn found that a change of frequency had negligible effect on electrical thresholds. Furthermore, the threshold values varied primarily as a function of the square wave duration.

Four recent studies were those conducted by Hawkes and Warm (1960, 1960, 1961, 1961) at the University of Virginia on the parameters of electrical cutaneous stimulation. In a study on the sensory range of electrical stimulation Hawkes and Warm used continuous sine-wave stimulation at varying frequencies. Current was increased until the reaction level (RL) of tingle was reported by the observers. Increases in current were continued until pain and finally, the tolerance limen (TL) was reported. Electrodes were placed on the finger pad and heel of the palm. The data are presented in Table 1.

Table 1

Composite of Hawkes' and Warm's Data

Frequency (Hzs)	Threshold Intensity (milliamps)		
	Tingle (RL)	Pain	TL
100	0.3	1.0	1.7
500	0.5	1.5	2.2
1,000	0.8	2.0	3.0
5,000	1.8	5.6	7.0
10,000	2.5	10.0	12.0

In all instances more current was required for reports of pain than tingle, and more current was necessary for the TL than for the RL and pain. Furthermore, more current was necessary to reach threshold at the higher frequencies of stimulation than at the lower ones. Qualitatively, tingle was reported as a weak sensation localized in one area under the active electrode. Pain was typically reported as a localized sensation superposed on the tingle and described as similar to the jab of a needle. The tolerance limen was reported as a burning sensation. Little or no change in the quality of sensation was reported with a change in frequency.

The second study by Hawkes (1960) was on the identification of intensity levels and channel capacity. He assumed that the number of possible absolute identifications of current intensity levels might be explained with respect to both the percentage of correct identifications and the amount of information transmitted to an observer. He found three intensity levels for maximum transmission at 1500 Hzs which would be useful in a communication system requiring perfect accuracy.

In another study (Hawkes, 1961) to determine the number of possible absolute identifications of electrical cutaneous stimulus durations and their channel capacity, Hawkes used eleven stimulus durations within a range of 0.5 to 1.5 seconds and 100 msec. apart. Twelve observers were used with electrodes placed on the finger and palm. With an alternating current frequency of 100 Hzs and a stimulus intensity of 6 db. he found that maximum channel capacity for absolute identification of duration was reached with the use of three duration levels.

Finally, in a study of discrimination with three standard stimulus durations of 0.5, 1.0, and 1.5 sec. intervals and intensity levels of 120, 160 and 200 per cent of RL at a frequency of 100 Hzs, Hawkes and Warm (1961) found that TL was affected most by the intensity level then by the signal duration. Poor discrimination resulted from the use of weak stimulus intensities or very brief durations of 0.5 seconds or less. The investigators felt that any coded system for communication should be dependent upon intensity and duration while frequencies should be constant.

Studies by Gilmer et al (1961) were undertaken concurrently with those of Hawkes using square-wave pulse generators as the stimulus source. Their apparatus was adapted from Hahn (1958) and altered so that the capacitance and resistance of the skin did not distort the wave-form. Exploratory investigations were made on 200 subjects and final studies on 12 trained observers. Exploration of most of the body surface was made noting the perception of pain and painless pulses under conditions of normal skin temperature, and under conditions of vasodilatation and vasoconstriction. The only portion of the skin not affected by neurovascular change was found to be the palms of the hands and the soles of the feet. The thresholds were almost constant in these areas and bilateral equivalence in pulse limens for the two palms were also found.

Gilmer and Haythorne (1941) showed that under certain conditions stimulation of the skin with sinusoidal current could destroy epidermal and dermal tissue. However, they were able to stimulate on the palm of the hand for up to two hours with no diminution of sensitivity, no change in current or voltage due to cutaneous change, and without creating local irritations. Adaptation could be handled by proper timing between pulses.

In a study by Croner (1961) on thresholds, pilot studies indicated that the range of durations which reliably mediate painless sensation was from 0.5 to 75.0 msec. Pulse durations shorter than 0.5 msec. resulted in perception of sharpness and pain, while durations longer than 75.0 msec. often lead to unpleasant burning sensations. The investigator found that both the voltage and current required to reach the pulse limen and the pain limen were highest at the shortest duration. The observers reported that the pulses of shorter duration are subjectively inferior to those of the longer duration. The most effective duration was about 10.0 msec. These pulses are easily discriminated and are not too long for communication systems.

Gilmer found that two levels of intensity could be easily discriminated with accuracy. A low, medium and high level could be easily identified from day to day without resorting to a reference point. For skin loci, when located, it was possible to reproduce the same pulse durations day after day with high reliability. Also neurovascular changes and perspiration had little effect on these areas after a short interval of time had been allowed for skin resistance to level off.

Repetition rates (frequency) can be discriminated but other problems exist in using this dimension in coding. First, frequencies exceeding 8 to 10 Hzs cause some discomfort and higher intensities cause pain. Second, an increase in the repetition rate of electrical square-wave stimulation leads to the perception of an increase in intensity as well as frequency, a phenomenon also observed in mechanical vibration. Confusion could well result if both intensity and frequency are used as coded dimensions.

Durations are not nearly so accurately discriminated as are intensities. It is possible, however, that two discriminatable levels of duration associated with a secondary dimension of skin "depth" can be found. Thus, with three levels of intensity, six loci (three on each palm), and two "duration-depth" dimensions, a code made up of thirty-six discrete symbols is possible. This would allow for an alpha-numeric code of twenty-six letters and ten digits.

In summary, although much work has been done on the identification of stimulus dimensions of mechanical vibration, more research is needed in the areas of channel load, distraction effect, and error range. Research using electro-pulse stimulation still lacks sufficient psychophysiological data on the boundaries between painless and painful pulses, conditions and effects of intensity, polarity, duration and intervals of pulses, and the types, sizes, and spacing of electrodes. Common to both mechanical and electro-pulse methods are the problems of language coding and complex information processing.

In 1966, the author investigated the psycho-physiological parameters of electrodermal stimulation (Hicks & Kheder, 1968), see Appendix I. The purpose of that study was to determine the parameters of electro-dermal stimulation as to: (1) the psychophysical parameters of the stimulus, (2) the physiological changes induced by the stimulation, and (3) the subjects' autonomic response to stimuli.

Eight subjects responded to an electrodermal stimulus of minimal intensity presented by the method of limits. The stimuli varied in: (1) a range of pulse repetition frequencies; 50, 75, 100, 200, 500, 700, 900, 1000, 1500, 2000, 2500, 2700, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10,000 Hzs and (2) duty cycle, either 5, 50, or 95 per cent. (Duty cycle is the percentage of on-time in relation to the amount of off-time in any one period, onset of one rising waveform to the onset of the next rising waveform). Each subject was tested on all the frequencies for each of the three duty cycles. The frequencies per duty cycle were presented in three different orders: (1) ascending, (2) descending, and

(3) randomly. The frequency, duty cycle and order of presentation were unknown to the subject. The stimulus generator was a Tektronix 160 series. During stimulation the subject's skin resistance, skin vasoconstriction and dilatation, heart rate and finger temperature were constantly recorded.

The results of the study are:

(1) The subjects' mean response levels for the different duty cycles over the same frequency ranges were significantly different (level of confidence below 0.05 as determined by multiple t-tests).

(2) The subjects' skin resistance increased after being stimulated with a frequency between 50 to 2000 (PRF) at the 5 per cent duty cycle only. All other duty cycles, 50 and 95 per cent were followed by a decrease in skin resistance.

(3) After electrodermal stimulation, there was a significant 10 per cent increase in vasodilatation and a 12 per cent increase in heart rate without differentiation to the frequency of the pulse train or its duty cycle.

(4) There were no significant changes of finger temperature.

The conclusion of this study was that the conduction mechanism of the skin could be compared to a "strength-duration curve" of a single neuron. ("A strength-duration curve is the relationship of the strength of the stimulus to the time during which it acts, Gardner, 1963, p.102.") The 95 per cent duty cycle with its long "on-time" may be causing a considerable amount of neuronal accommodation. Therefore, more current is needed to stimulate hyperpolarized neurons. As the frequency increases, there is less and less real "off-time" and more current is needed to produce stimulation. This would also be true for the 50 per cent duty cycle but to a lesser extent than in the 95 per cent duty cycle.

The five per cent duty cycle appears not to produce this effect because of its constant level of intensity (ma) across the frequencies 50 to 6000 Hzs (above 6000 Hzs the subjects did not indicate the presence of the stimulus even when the stimulus generator was at maximum output). The five per cent duty cycle may cause some depolarization, in which case the neurons would be more excitable than in their normal resting state. The long "off-time" would dissipate any accommodation effects. With higher frequencies, beyond 6000 Hzs, another effect occurs. The current has to flow for a particular period of time in order to be effective. If the current is turned on and off rapidly, current lasts such a short time that it will not stimulate, no matter what its strength/power. Therefore, the finite period of current "on-time" for the skin must be in excess of 8.333 microseconds.

This investigation uses a five per cent duty cycle at 3000 Hzs as the independent stimulus. The reasons for this choice are: (1) the signals need minimum current to reach a detectable level, (2) the signal produces the least physiological change, (3) post experimental inquiry of the Os suggests that habituation to the signal does not occur, and (4) the signal appears to be stable in that it has the least amount of individual differences.

Auditory

Unlike that of the cutaneous sense, the study of audition has a long and rich history. "The physics of acoustics was well advanced by 1800, and the anatomy of the external and middle ears, as well as the gross structure of the inner ear, was fairly well understood (Boring, 1957, p.106)." In 1970 alone there were over 320 articles published on audition. Consequently a comprehensive review of the literature is beyond the scope of this thesis. Rather, a selective review is presented of only those studies that are particularly relevant to this investigation. The goal of this thesis is not to study the mechanism of audition per se but to use varied auditory signals as a means of determining how humans process auditory information. It is the processing mechanism that is of interest, not how the O identifies different physical parameters of the signal, e.g., waveform or rise time. Therefore, only studies on how humans process auditory information are reviewed.

Theoretical Issues of Auditory Psychophysics

Recent evidence indicates that serious difficulties are encountered when complex perceptual processes are investigated using traditional Weber-Fechner psychophysical methods (Holtzman, 1965). Goldiamond (1958) discussed the dependence of results on the method used to establish a threshold. Corso (1963) has reported that the method of adjustment and the method of limits produced different auditory thresholds when the same subjects were tested under both conditions. Clearly, different methods of obtaining thresholds do result in different limen values. An obvious consequence of the method-specific nature of thresholds is that results from experiments using different procedures are not directly comparable, since there are differences in the methods of obtaining the threshold values.

Investigators have long recognized the arbitrary, statistical nature of the threshold. One definition of threshold states that it is a point in a stimulus continuum which produces a given response 50 per cent of the time (Guilford, 1954). There is no prior basis for adhering to this arbitrary definition (Bilger, 1964). Empirically, it is possible to define a threshold as any point in the stimulus continuum which elicites a response anywhere in the range from chance to perfect performance. Confusion occurs when the threshold is erroneously interpreted as an arbitrary point above which detection of a stimulus occurs, while no detection occurs below it (Goldiamond, 1958). "Subliminal" stimuli are detected a measurable percentage of time. Detection of "subliminal" stimuli is especially frequent if the threshold is defined at levels well above chance performance (Eriksen, 1960).

A further difficulty arises because of the widespread use of "corrections for guessing". Corrections for guessing are assumed to produce a better estimate of the observer's sensory capabilities. Hake and Rodwan (1967) have argued that none of these correction factors are valid.

The "error of habituation", as defined by Hake and Rodwan, is a subject's unwillingness to respond to a stimulus until the evidence for its presence is great. Conversely, the same investigators define "error of anticipation" as the tendency of the subjects to respond affirmatively to the presence of stimuli on the basis of minimal evidence. Observers committing the "error of anticipation" appear to have much greater sensitivity when the threshold framework is applied. This is the case because no account is taken of the increased false detections, which typically accompany an increase in apparent sensitivity due to "anticipation errors". On the other hand, observers committing the "error of habituation" show spuriously low sensitivity since a lowered accuracy results from this type of error. Thus both correct and false detections must be accounted for in any adequate description of the observer's perceptual performance (Swets, 1961).

One solution for this difficulty has been to use well trained observers to ensure a reasonably constant subjective criterion. In investigations of personality and perception, however, the observer's criteria for responding to stimuli are determined both by his motivation and his sensory acuity. Bernstein and Eriksen (1965) suggested that perceptual defence studies, using stimuli of a sexual nature, resulted in poor sensitivity. In fact, the data may reflect the observer's unwillingness to report a perception of such stimuli until a high degree of confidence is reached.

The importance of the subject's confidence, for <u>any</u> perceptual task, lies in the distinction between the observer's sensitivity and his criterion for reporting the presence or absence of a stimulus. In addition to the methodological problems described above, no distinction has typically been made between sensory and nonsensory aspects of the observer's performance. Investigators in the area of psychophysics have long been aware that the observer's subjective standard or criterion for reporting the presence or absence of a stimulus affects the obtained value of a threshold, e.g. Fechner's negative sensations (Boring, 1920; George, 1917; Guilford, 1927; Thompson, 1920). As an example, "errors" of traditional psychophysical practices directly affect the values of a threshold. Such values obtained by the method of limits are affected by a reluctance of the observer to report the presence of a stimulus until the evidence for its presence is great, or the observer's willingness to respond affirmatively to only minimal stimulation. The subject's sensitivity and his criterion for reporting the presence or absence of a stimulus are confounded in traditional psychophysical methods. Swets (1961) has argued that a difference between estimates of two thresholds can be attributed to a change in sensitivity only if it is assumed that the observer's criterion is held constant. Therefore, traditional threshold techniques are ambiguous since they do not distinguish between: (1) actual differences in sensitivity, (2) differences in the criteria used to report the presence of a stimulus, or (3) a combination of both sensitivity and criteria for reporting the stimulus.

The general problem of detecting sensory stimuli in the threshold region has been investigated in various vigilance studies (Buckner and McGrath, 1963; Loveless, 1967; Osborn, Sheldon and Baker, 1963). These investigators studied the performance of untrained observers on vigilance tasks and human performance tests rather than comparing responses in different sensory-motor modes of judgment. Results show that a noticeable improvement in performance occurs when the observers are given redundant information in the form of simultaneous auditory and visual displays (Brown and Hopkins, 1967). However, Buckner and McGrath (1963) predicted the possibility of independent operation of these two sensory channels, but did not obtain good experimental verification of their prediction, using a vigilance task.

Interaction between different sensory modalities generally involves the problem that dual sensory input enhances signal detectability. Brown and Hopkins (1967), in a study on the interaction of the auditory and visual sensory modalities, found that redundant sensory information produces improved human signal detection performance. Increases in signal detectability result from simple probabilistic adding of the responses of two independent sensory systems. The authors concluded that there is no apparent interaction between the visual and auditory information-processing systems.

Directly Relevant Experiments

Stevens (1959) constructed ratio scales of subjective intensity on three perceptual continua—loudness, vibration and electrical shock. In turn, the obtained scales were used to predict what Stevens considered a direct match between pairs of sensations on these continua.

Stevens used numerical ratio scales of subjective magnitude for three modalities (loudness, mechanical vibration applied to the finger tip, and electric shock applied to the fingers) to predict the form of the equal-sensation functions resulting from the pairs of sensations. For example, loudness was adjusted to appear equal to a given vibration on the finger or to an electric shock to the fingers. Cross-modality matches were made between each and every modality. A stimulus from a given modality served once as the standard and once as the dependent variable.

The experimental curvatures for cross-modality matches closely approximated the predicted values. From the results, Stevens concluded that scales obtained by magnitude estimation can be used to predict the form of the equal-sensation functions, which seems to attest to the validity of subjective estimates.

Stevens' study demonstrated that subjects can establish subjective cross-modality equivalence scales with a reasonable degree of validity. Therefore, Stevens (1959) has shown that the sensation scale of one modality can be compared to that of another modality. Furthermore, Eriksen (1960) and Guilford (1954) contend that stimuli below an arbitrary threshold are also detectable.

Based upon these views, Hicks (1969) designed an experiment to evaluate the accuracy between cross-modality matches of auditory magnitudes and overt verbal judgments in the assessment of the same electrodermal stimulation (see Appendix II). The study also determined the practicability of using one sensory modality to rate the stimulus magnitude subjectively in another modality.

The independent variables were the electrodermal stimuli, which were randomly presented 50 per cent of the time; the other 50 per cent were catch trials. The dependent variables were: (1) vocal confidence ratings, and (2) auditory matched magnitudes (measured in relative decibels or voltages).

The observers' detection of the presence of electrodermal stimulation can vary from absolute certainty to chance performance. Once cross-modality matches had been obtained, the observer (O) vocally reported his degree of confidence as to whether the same electrodermal stimulus was present (a dual series task for each stimulus). Confidence ratings were given as a percentage of certainty as rated subjectively by the O. It was then possible to compare the probabilistic accuracy of the vocal confidence rates and auditory magnitude matching to the same electrodermal stimulus.

The intensity (milliamperes) of the electrodermal stimulus, later used as the standard stimulus, was established at a reference point that evoked a response 50 per cent of the time by the method of limits. Once this intensity level had been established its value was maintained throughout the experiment.

During the training period, Os matched the loudness (amplitude) of the Gaussian noise (GN) to the intensity of varying electrodermal stimuli (EDS). From the result, an equivalence scale was established between the auditory and cutaneous senses of each O.

This study not only presented sensory stimulation within the "threshold" region but also asked the O to manipulate an auditory signal in his so called "threshold" region by: (1) matching the loudness (amplitude) of GN to the perceived intensity of the electrodermal stimulus, and (2) giving confidence ratings as to the presence of an electrodermal signal. The amplitude adjustment of GN, during some trials, was below the traditional "threshold" level in what was previously considered a subliminal area. Therefore, the O was manipulating the amplitude of GN below what was previously considered his "threshold". (The word "threshold" is an arbitrary mathematical construct and it also infers a Weber-Fechner framework of reference; consequently, future reference to "threshold" is not made unless referring to its classical tradition).

This study applied signal-detection theory (Tanner, Swets and Green, 1956; Tanner and Swets, 1954) and nonparametric statistical techniques to measure the parameters of the vocal confidence ratings as well as the cross-modality matching between an auditory loudness (amplitude) and an electrodermal stimulus. This is a fundamental detection problem consisting of an observation (an event) occurring in a fixed length of time, in which a decision is made as to whether the interval contained only noise or a signal as well.

A "Receiver-Operating-Characteristic" (ROC) curve was established for the three different response modes: (1) auditory matching alone, (2) auditory matching accompanied by vocal responses and, (3) vocal confidence ratings. Unfortunately, the slopes of the ROC curves did not equal one; therefore, the area under the curve was calculated.

Since the area under each curve is larger than the area under the negative diagonal, each O was able to differentiate the presence and absence of shock better than by guessing. Verification of a systematic response mechanism was obtained by a Chi Square analysis for all three response categories, which were significantly different ($p < 0.001$), indicating that Os' detection accuracy was considerably better than chance (50 per cent) detection.

The area under the curve was used as a comparison for the different responses by a Friedman Two-Way analysis of Variance. The greater the area under the curve the more sensitive is O in separating signal from noise. The Friedman Two-Way Analysis of Variance is significant at the 0.042 level of probability.

For all Os, the verbal responses were more accurate in detecting the presence or absence of shock than the accuracy of their auditory matchings. Also, results from 3 out of 4 Os had a larger area under the ROC curve for the auditory matching accompanied by vocal responses, than for the isolated auditory judgments. Therefore, Os were more accurate in detecting shock when auditory matching was accompanied by verbal responses than when it was not.

These results demonstrate that Os are extremely effective in manipulating the Gaussian noise throughout their sensory probabilistic zone. These results are contrary to the classical notion of threshold as a point, not exactly constant but nearly so, above which sensory differences vanish in the "unconscious". This experiment clearly demonstrates that Os are capable of perceiving and manipulating signals throughout their sensory probabilistic zone and that they respond affirmatively only when the signal strength exceeds some subjective criteria.

In conclusion, the Os had the most difficulty in gathering and processing those sensory data that were not verbally coded. Apparently, verbally coded material is more easily stored in memory and can be processed more accurately than sensory data. Once auditory information is coded into speech patterns, it seems to influence other sensory judgments, thereby increasing the accuracy of the auditory matchings that accompany the vocal ratings. This effect can be attributed to either or both of two possible failures in the course of human information processing. First, if Os do not perceive the auditory stimuli accurately, they may assign less diagnostic value to the data than they in fact should. Diagnosis is the process whereby the O assigns relative values to the auditory signals. Or, secondly, Os may be unable to integrate auditory information (over time) properly even though they may perceive the diagnostic value of any specific data correctly. Integration is the process whereby the O combines, organizes or co-ordinates previously diagnosed auditory information. Therefore, since speech-coded data appear to be less affected by failures in information processing, as determined by the area under the ROC curve, information that is verbally coded can influence accompanying sensory data, thereby increasing its detection accuracy.

The results of this study provide the framework for numerous questions:

(1) Why does verbally coded material produce greater sensitivity in the detection of EDS than the auditory matching?

(2) Why do speech patterns influence sensory judgments?

(3) Do Os assign the appropriate relative value to the auditory signals? In other words, do the Os diagnose auditory stimuli correctly?

(4) And/or, are Os unable to integrate auditory information correctly even though they may perceive the diagnostic values of any specific data correctly?

The objective of experiment one is to attempt to answer the above questions.

Chapter 3

Method

All three experiments used modifications of the same apparatus and procedure.

Apparatus

Each observer (O) was seated in a quiet room with his back to the experimenter. For EDS, two electrodes were positioned on the left hand. The positive electrode, made of conductive vinyl, 1.2 cm. in diameter, was placed on the middle phalanx of the index finger. A similar electrode, positioned to the middle finger, was the ground. A signal generator produced 3000 Hzs. at a five per cent duty cycle. The amplitude of the signal was maintained by a variable voltage regulator. The standard (later used as the independent variable) electrodermal intensity, expressed in volts, was determined by the method of limits using ascending, descending and random procedure and was established at the fifty per cent response level for each O.

The GN was produced from a Peters AP/6 clinical audiometer and controlled by its attenuator. GN was presented to each O through dichotic earphones. The attenuator of the audiometer was connected to a gear reduction device and used by O to control sound level, with visual cues removed. A Hewlett Packard 3400 A Root Mean Square meter connected across the earphones indicated sound level, see Appendix III.

Procedure

During the training session, O was instructed to match the loudness of the noise to varying magnitudes of EDS. Repeated testing produced a stable loudness continuum of noise for corresponding changes in EDS intensity. At high levels of EDS, the O selected louder GN, while for less intense stimuli, he chose quieter noises. Consequently, an equivalence scale could be and was established between various levels of shock and sound. When the experiment began, the EDS level was held constant at the O's fifty per cent response level; O had no knowledge that the EDS was being held at a constant intensity. Hence, the GN level selected by the O can be used to determine his level of confidence or certainty as to the presence or absence of EDS.

The shock was presented in an automated random order with catch trials fifty per cent of the time, the pattern unknown both to O and to the experimenter. The O was simply told to; (1) adjust the loudness of the GN to be equivalent to the perceived magnitude of the shock, and on selected sequences (2) verbally rate how confident he was that a EDS was or was not present.

Upon illumination, a white light, O could press a button to start the trial. When the button was pressed it caused a green illumination together with presentation of the GN and EDS. On selected sequences the green light was interrupted by a red light indicating that the variable loudness of the GN was now being replaced by GN that was stable at the level of the O's fifty per cent response (as previously determined). This was the anchor point. On selected sequences, the O gave his verbal confidence rating (VCR) after the green light was extinguished. VCRs were represented along a continuum from zero to 100 per cent, where zero to 49 represented decreasing confidence that EDS was absent and 51 to 100 increasing confidence that EDS was present. The sequence of events for each O was:

1. The O sat in front of a control panel containing attenuator and indicator lights;
2. The O's right index and middle fingers, middle phalanx, were vigorously rubbed with Cambridge electrode jelly in order to reduce skin resistance. The O placed these two fingers on a grooved sponge containing the electrodes;

3. Earphones were placed on the O and he was shown how to use the attenuator and warned that any accidental visual markings or proprioceptive feedback from the fingers could result in errors. The only criterion for the O's decision was the loudness of the GN. The specific significance of each of the different coloured lights was explained.

The sequence of events for the experimenter was:

1. The experimenter, separately controlling both the intensity of the EDS and the GN, established the fifty per cent response level of the observer for both modalities, using the method of limits;
2. The O was asked to match the loudness of the GN to the intensity of the EDS. This routine was continued until the O could produce approximately the same amplitude adjustment for a given EDS. The training session needed was approximately two hours long.

Chapter 4

Experiment One

Introduction

The 1969 study concluded that the O has one or both of two difficulties in processing auditory information. First, the Os may assign the inappropriate value to the auditory stimuli; i.e., the Os might not diagnose the auditory signals correctly. Second, the Os may have difficulty integrating correctly diagnosed auditory information, i.e., the Os erroneously combine or organize the auditory information. This experiment attempts to determine whether or not either or both of these difficulties are encountered during the processing of auditory information. An illustrative example of the differences between diagnosis and integration is as follows: A driver begins to overtake a lorry. Another vehicle approaching in the opposite direction now appears on the horizon, causing the overtaking driver to make a decision. He can pull back behind the lorry or he can continue to overtake it. The driver must evaluate his own vehicle's speed and the speed of the oncoming vehicle (diagnosing speed of closure). The driver must now evaluate his accelerating speed and the lorry's speed (second diagnosis) and then decide if his vehicle would be in front of the lorry before he reached the oncoming vehicle (integration).

If the O is having difficulty in the diagnosis of auditory stimuli, then, when an aid in diagnosis is provided the O's performance should improve. When the O wants to set the GN loud enough to reflect a decision that a signal is present, he must adjust the magnitude of the GN to exceed his 50 per cent level of response. Conversely, if the O wants to set the GN to reflect a decision that only noise is present he must reduce the GN loudness to be below his 50 per cent level of response. Conceivably, if the O has lost his inherent reference point, he may set the GN loudness at a level he thinks is above his 50 per cent level of response when, in fact, it is actually below it, resulting in an error. Similarly, errors could be made in the opposite direction. A simple solution to this problem is to indicate the O's 50 per cent level of response to him (an anchor point) on each trial. Subsequently, if the O is having difficulty in diagnosing the auditory information an anchor point could be a diagnostic aid.

The Os may have difficulty in integrating the correctly perceived auditory information. To test this postulate the Os can be provided with a device which will help them to integrate the auditory information. In the

1969 study an interaction occurred between the CMM and the VCR. Possibly the VCR is an aid to integration. If it is true that the VCR interacts with the accompanying CMM, then they will also affect subsequent CMM tasks, since the knowledge of the VCR scale is not eraseable. Thus knowledge of the verbal rating scale (VCR) may be expected to improve the detection accuracy of the accompanying and subsequent CMM for an O who has difficulty in integrating auditory information. The assumption is that with the help of the rating scale the O is capable of arranging, combining and organizing the incoming auditory information better than he would without any such conceptual scale. Of course, the O might develop his own scale, but the VCR closely resemble the CMM task and the O is asked for his confidence ratings at the end of each trial. Thus the VCR should reflect greater efficiency at integration both because of their similarity to CMM and because they are a means of communication. Also, if the integration of auditory information is a problem and the VCR aids auditory organization, its effects should subsequently affect other treatments.

If the Os have difficulty in both diagnosis and integration, there should be an additive effect when both the auditory anchor and the knowledge of VCR scale are present.

There are other problems that should be considered; namely, practice effects, experimenter effects, and treatment residual effects. Will practice affect the trained O's ability to detect signal from noise only? Previous studies (Swets and Sewall, 1963) using a sinusoidal signal in noise and a forced-choice procedure found that practice effects are limited to the first session. Since this study uses GN and a rating procedure, it is important to know whether or not there are practice effects.

It is equally important to identify any effect which the experimenter may have upon the O's ability to separate signal from noise. According to signal detection theory the experimenter can affect the slope of the ROC curve but can not affect its height (Green and Swets, 1966). During the second half of the experiment the O was erroneously informed as to his performance by the experimenter (Table 2). O was informed that his CMM was now better than his VCRs. Previously (1969 results) the VCRs were considerably better than CMM. Can the experimenter's erroneous feedback alter the results?

Whenever the same Os are given a series of different treatments there is danger that the sequence in which the treatments are given could produce an effect (residual transfer). Therefore, the Os were presented with treatments in different sequences. The sequences were altered as much as the total experimental design would allow, (see listing below, Table 2). Experiment one is designed to determine the effects of practice, residual transfer and the influence of the experimenter upon the Os' performance. In the order of analysis, experiment one is an investigation of the following questions:

1. Does practice have an effect?
2. Does the experimenter have an effect?
3. Does each of the different treatments have a residual effect?
4. Does the presence of an auditory anchor point aid the O's diagnosis of the sensory auditory stimuli?
5. Does the knowledge and use of the VCRs aid integration of the auditory information for the CMM?
6. Does the knowledge of the VCRs carry-over to unaccompanied CMM trials?

Method

Subjects

Seven male adults and one female adult were tested, none of whom reported a history of otologic or neurologic disease. The Os' performances were maintained at an asymptotic level by offering 0.50 np for each correct response and penalized 0.50 np for each incorrect response (Lukaszewski and Elliott, 1962; Blackwell, 1953). Each O was informed about his performance after every 35 trials. Each O returned to the laboratory for eleven sessions. Each session was two hours long. Total experimental time was 176 hours.

Apparatus

As outlined in the Method chapter (p.62).

Procedure

As outlined in the Method chapter (p.63) and Fig. 2 (p.12).

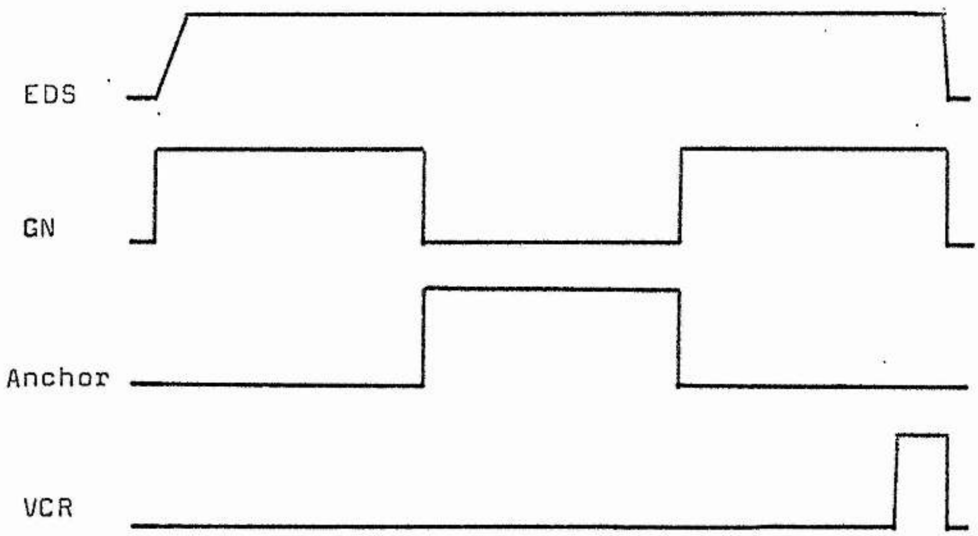


Fig. 3. The sequence of experimental events for each trial.

Experimental Design

The first two sessions (A and B) and resulting data are not completely comparable with later sessions and data because the O did not at first have knowledge of the VCR scale. Knowledge of the VCR scale could affect subsequent CMM tasks. Question six concerns this hypothesis. The first session (A) used only CMM. The second session (B) employed CMM with an auditory anchor. The O was informed as to the VCR scale for the first time in session three, Table 2.

Table 2

Experimental Design

Conditions											
Experimenter Provides Correct Feedback						Experimenter Provides Erroneous Feedback					
Nonanchored			Anchored			Nonanchored			Anchored		
CMM+VCR		CMM	CMM+VCR		CMM	CMM+VCR		CMM	CMM+VCR		CMM
C	D	E	F	G	H	I	J	K	L	M	N

Four different condition sequences were presented to the eight Os:

1. ABCDEFGHIJKLMN for Os; B.W. and Y.B.
2. ABFGHCDEIJKLMN for Os: L.S. and M.R.
3. ABFGHCDELMNIJK for Os; D.P. and B.G.
4. ABCDEFGHLMNIJK for Os; J.F. and A.R.

In conditions A and B the experimenter provides the correct feedback but the Os did not have knowledge of the VCRs. An anchor was presented in condition B; whereas, A was nonanchored.

Results

Data

The data from each O is analysed by signal detection theory. The O's loudness continuum, expressed as root mean square voltages, is represented along the ordinate, the dependent variable. The VCR continuum is also represented along the ordinate as percentages. The abscissa is divided into two categories, which are the independent variables: (1) trials when the EDS was present - signal plus noise, and (2) trials when no EDS was present - noise only. The auditory voltages, or the VCR, for both signal plus noise and noise only are plotted along the ordinate observing the appropriate category (signal plus noise or noise only). The plots are two separate continua, one showing signal plus noise and the other showing noise only. Where these two continua overlap, accumulative probability functions are calculated:

First Co-ordinate

$$S_1 = \text{Signal + noise}_1 = \text{Subtotal}_1/\text{Total}_S = PS_1$$

$$N_1 = \text{Noise only}_1 = \text{Subtotal}_1/\text{Total}_N = PN_1$$

Second Co-ordinate

$$S_2 = \text{Signal + noise}_2 = \text{Subtotal}_2/\text{Total}_S = PS_2$$

$$N_2 = \text{Noise only}_2 = \text{Subtotal}_2/\text{Total}_N = PN_2$$

As many co-ordinates as possible are determined, the number being dependent upon the degree of overlap between the two continua.

On metric graph paper, equal units are arranged along the ordinate and the abscissa. The ordinate represents the probability density for all values of GN when EDS is present. The abscissa represents the probability density for all values of GN when EDS is absent.

A convergent point between PS_1 (ordinate) and PN_1 (abscissa) is plotted on metric graph paper and successive points are similarly plotted. The points are integrated and the ROC curve is established (Green and Swets, 1966).

The area under the ROC curve (Ag) was determined by counting the square millimeters on the graph paper. "A valuable nonparametric measure of performance is the area under the ROC curve, Ag .... an advantage of Ag is that it can be used to compare performance across conditions for which different distributional assumptions may be necessary (Banks, 1970, p.85)." In order to avoid possible inaccuracies in determining Ag, (due to the effects of the width of the pencil line and the author's degree of visual acuity), an error factor was allowed, and taken to be plus or minus fifty square millimeters. Hence, conditions valued within fifty square millimeters of each other were considered to be ties, Table 3.

Table 3

Area Under the ROC Curve

Os	A	B	C	D	E	F	G
B.W.	6752	6785	5610	6542	6194	7845	8302
Y.B.	6142	6945	6711	7116	6305	6534	6088
L.S.	8334	8726	8097	8408	8106	8416	8704
M.R.	7901	8995	7124	7299	7845	7693	7652
D.P.	7413	7747	6560	6946	7708	7138	7270
B.G.	6074	7407	7138	7357	5813	6882	6612
J.F.	7677	9046	9318	9602	9242	9608	9705
A.R.	6315	6316	5893	6192	6292	7854	7761

Os	H	I	J	K	L	M	N
B.W.	7310	5609	5903	6591	8168	8438	6281
Y.B.	5742	7630	7759	7005	9172	9374	9280
L.S.	7850	6340	6497	6825	8779	8947	9183
M.R.	7223	7825	8095	7277	6615	6504	7264
D.P.	5667	5977	6019	6270	6537	6664	5742
B.G.	7494	6977	6718	6197	7142	6890	7062
J.F.	9527	9846	9920	9334	9554	9577	9800
A.R.	6225	5308	4881	5640	5855	5927	4758

Practice Effects

Null Hypothesis. H_0: there will be no practice effect during the entire experiment. H_1: O's performance for detecting the presence or absence of the signal improves as the number of trials increase.

Statistical Test. Because each O was assessed under different conditions (related samples) and because Ag is nonparametric (Banks, 1970), the nonparametric Friedman two-way analysis of variance was chosen.

Rejection Region. The region of rejection consists of all values of X_r^2 which are so large that the probability associated with their occurrence under H_0 is equal to or less than $\alpha = 0.05$.

Statistical Conclusion. Three times during the experiment, sessions A, E and K, each O performed simple CMM in the absence of any other experimental condition. In conclusion, there are no significant practice effects.

Table 4

Practice Effects

Observers	Sessions A	E	K
1. B.W.	6752	6194	6591
Rank	3	1	2
2. Y.B.	6142	6305	7005
Rank	1	2	3
3. L.S.	8334	8106	6825
Rank	3	2	1
4. M.R.	7901	7845	7277
Rank	3	2	1
5. D.P.	7413	7708	6270
Rank	2	3	1
6. B.G.	6074	5813	6197
Rank	2	1	3
7. J.F.	7677	9242	9334
Rank	1	2	3
8. A.R.	6315	6292	5640
Rank	2.5	2.5	1
Rj	17.5	15.5	15

$$X_r^2 = 12/N.k\ (k+1) \quad Rj - 3N\ (k+1)$$

where N = number of rows

k = number of columns

Rj = sum of ranks in column j

= sum all k conditions

$= 0.37 \qquad 0.794 > p < 0.967$

Experimenter Effects

Null Hypothesis. H_0: the experimenter has no effect on the experimental conditions. H_2: the experimenter has an effect upon the performance of the Os.

Statistical Test. Friedman two-way analysis of variance.

Rejection Region. The same region of rejection as for the practice effect (p. 77).

Statistical Conclusion. In the Hicks, 1969, study the VCRs were more accurate at detecting the presence or absence of signal than the CMM. After every 35 trials the Os were informed as to their performance, e.g., "15 correct CMM and 19 correct VCR." During the second half of the experiment, the experimenter incorrectly informed the Os as to their performance, e.g., "now have 19 correct CMM and only 15 correct VCR." The experimenter's erroneous feedback was a deliberate attempt to manipulate the O's performance and to affect their results by inducing an artificial improvement in the CMM and/or a corresponding decrement in VCR. During the first half of the experiment the O was correctly informed as to his performance, whereas during the second half of the experiment the O was deliberately misinformed as to his performance.

In conclusion, there is no significant experimenter effect for either the nonanchored or anchored task, Tables 5 and 6.

Table 5

Experimenter Effect I

	Nonanchored					
	Correct Feedback			Erroneous Feedback		
Os	CMM + VCR		CMM	CMM + VCR		CMM
1. B.W.	5610	6542	6194	5609	5903	6591
Rank	1.5	5.5	4	1.5	3	5.5
2. Y.B.	6711	7116	6305	7630	7759	7005
Rank	2	4	1	5	6	3
3. L.S.	8097	8408	8106	6340	6497	6825
Rank	4.5	6	4.5	1	2	3
4. M.R.	7124	7299	7845	7825	8095	7277
Rank	1	2.5	4.5	4.5	6	2.5
5. D.P.	6560	6946	7708	5977	6019	6270
Rank	4	5	6	1	2	3
6. B.G.	7138	7357	5813	6977	6718	6197
Rank	5	6	1	4	3	2
7. J.F.	9318	9602	9242	9846	9920	9334
Rank	2.5	4	1	5	6	2.5
8. A.R.	5893	6192	6292	5308	4881	5640
Rank	4	5	6	2	1	3
Rj	24.5	38.0	28.0	24.0	29.0	24.5

$\chi_r^2 = 5.04 \qquad 0.50 > p < 0.70$

Table 6

Experimenter Effect II

	Anchored					
	Correct Feedback			Erroneous Feedback		
Os	CMM	VCR	+ CMM	CMM	VCR	+ CMM
1. B.W.	7845	8302	7310	8168	8438	6281
Rank	3	5	2	4	6	1
2. Y.B.	6534	6088	5742	9172	9374	9280
Rank	3	2	1	4	6	5
3. L.S.	8416	8704	7850	8779	8947	9183
Rank	2	3	1	4	5	6
4. M.R.	7693	7652	7223	6615	6504	7264
Rank	5.5	5.5	3.5	2	1	3.5
5. D.P.	7138	7270	5667	6537	6664	5742
Rank	6	5	1	3	4	2
6. B.G.	6882	6612	7494	7142	6890	7062
Rank	2.5	1	6	5	2.5	4
7. J.F.	9608	9705	9527	9554	9577	9800
Rank	2.5	5	2.5	2.5	2.5	6
8. A.R.	7854	7761	6225	5855	5927	4758
Rank	6	5	3.5	2	3.5	1
Rj	30.5	31.5	20.5	26.5	29.5	28.5

$X_r^2 = 0.78 \qquad p < 0.99$

Residual Effects

Null Hypothesis. H_0: the sequence of experimental treatments has no effect upon the O's performance. H_3: the sequence of experimental treatments does affect the O's performance.

Statistical Test. Friedman two-way analysis of variance.

Rejection Region. The same region of rejection as for the practice effect (p.77).

Statistical Conclusion. It is possible that with different conditions or treatment effects for the same Os, there is a transfer effect from one condition or treatment to the next. Consequently, the experimental tasks were altered, without disturbing other parameters, in order to test for any residual transfer. Four different experimental sequences were divided between eight Os. Sessions one and two were similar for all Os.

Table 7 shows that there are no significant residual transfer effects.

Table 7

Residual Effects

	Sessions							
Os	3	4	5	6	7	8	9	10
1.B.W.	5610	6194	7845	7310	5609	6591	8168	6281
Rank	1.5	3	7	6	1.5	5	8	4
2.Y.B.	6711	6305	6534	5742	7630	7005	9172	9280
Rank	4	2	3	1	6	5	7	8
3.L.S.	8416	7850	8097	8106	6340	6825	8779	9183
Rank	6	3	4.5	4.5	1	2	7	8
4.M.R.	7693	7223	7124	7845	7825	7297	6615	7264
Rank	6	4	2	7.5	7.5	4	1	4
5.D.P.	7138	5667	6560	7708	6537	5742	5977	6270
Rank	7	1	5.5	8	5.5	2	3	4
6.B.G.	6882	7494	7138	5813	7142	7062	6977	6197
Rank	3	8	6.5	1	6.5	5	4	2
7.J.F.	9318	9242	9608	9527	9554	9800	9846	9334
Rank	2.5	1	6	4.5	4.5	7.5	7.5	2.5
8.A.R.	5893	6292	7854	6225	5855	4758	5308	5640
Rank	4.5	7	8	6	4.5	1	2	3
Rj	34.5	29	42.5	38.5	37.0	31.5	39.5	35.5

$$X_r^2 = 2.75 \qquad 0.90 > p < 0.95$$

Anchor Effects

Null Hypothesis. H_0: the presentation of an anchor point representing the O's auditory, GN, cut-off point will not affect his performance, Ag, when compared to other treatments when no anchor point was present. H_4: the presence of an anchor will improve the O's performance, Ag, when compared to treatments without the anchor point.

Statistical Test. The Sign test was chosen because the samples are related and the treatments being considered are in pairs.

Rejection Region. Since H_4 predicts the direction of the difference, the region of rejection is unidirectional. It consists of all values of X (where X is the number of minuses) whose one-tailed associated probability of occurrence under H_0 is equal to or less than $\alpha = 0.05$.

Statistical Conclusion. All Os received the following conditions: A, simple CMM, and B, CMM with an anchor point, in the same sequence, A then B. Since all the Os had no previous knowledge of the VCR scale and had not experienced any other treatment, the first two sessions are unaffected by any other treatment. When the auditory anchor is present the Os are significantly ($p = 0.016$) better at detecting the presence of signal from noise than when the anchor point is not available.

An auditory anchor point does significantly increase the O's ability to separate signal from noise only. Twelve other treatments are paired for anchored and nonanchored treatments, Table 8.

Table 8

Anchor Effects

Conditions	Probability
Correct Feedback	
1) CMM accompanied by VCRs	
Sessions C vs F	0.035
2) VCRs, Sessions D vs G	0.035
3) CMM unaccompanied	
Sessions E vsH	0.500
Erroneous Feedback	
1) CMM accompanied by VCRs	
Sessions I vs L	0.035
2) VCRs, Sessions J vs M	0.035
3) CMM unaccompanied	
Sessions K vs N	0.656

The presence of an anchor point significantly increases the O's ability to detect the presence of signal from noise only for the VCRs and the accompanying CMM. Since the Os were given each test treatment twice and since both testings, correct and erroneous feedback, have the same results, the effect of the anchor point can be considered replicated. The unaccompanied CMM under both treatments, correct and erroneous feedback, never demonstrated a significant anchor effect.

The anchor produces a significant improvement in the CMM and VCR detection accuracy except when CMM is unaccompanied by a verbal rating. However conditions A and B (anchor vs nonanchor) are significantly different and at this stage the Os had no knowledge of the verbal rating scale. The only difference between conditions A-B and E-H, K-N is the Os knowledge of the verbal rating scale. Possibly there is some retention of information from the Os' knowledge of the VCR to the unaccompanied CMM.

VCRs Effects

Null Hypothesis. H_0: there is no difference between VCRs and the accompanying CMM. H_5: the VCRs are better at detecting the presence of signal from noise only than the accompanying CMM.

Statistical Test. Since the data is related to nonparametric pairs the Sign test is chosen.

Rejection Region. H_5 predicts the direction of the difference, thereby the region of rejection is unidirectional. The region consists of all values of X whose one-tailed associated probability of occurrence under H_0 is equal to or less than $\alpha = 0.05$.

Statistical Conclusion. Four times during the experiment CMM was accompanied by VCRs, Table 2 (p.73). In the nonanchored treatment, the VCRs are significantly more accurate than their accompanying CMM. However, when an anchor point is available for the CMM there is no significant difference between the VCR and CMM, Table 9.

Table 9

VCR Effect

Conditions	Probability
Nonanchored	
Correct feedback VCR(D) > CMM(C)	0.004
Erroneous feedback VCR(J) > CMM(I)	0.062
Anchored	
Correct feedback VCR(G) > CMM(F)	0.500
Erroneous feedback VCR(M) > CMM(L)	0.227

Carry-over Effects

Null Hypothesis. H_0: when the O has conceptualized and used the VCR scale, this knowledge does not affect the accompanying CMM nor is this knowledge utilized on subsequent sessions when CMM is unaccompanied by VCR. H_6: VCRs improve the accompanying CMM detection accuracy and the O's knowledge of this scale affects subsequent CMM tasks.

Statistical Test. For the same reasons as expressed under practice effect (p.77), a Friedman two-way analysis of variance was chosen.

Rejection Region. Same as practice effects (p.77).

Statistical Conclusion. Each O had four CMM tasks that were accompanied by VCR. In other words the O gave two responses for the same stimulus: (1) CMM and (2) VCR. After each of the four CMM tasks accompanied by VCRs, each O had a session of CMM that was unaccompanied by any other response. If the VCR does improve the accompanying CMM, does this improvement continue for/during the next task? By comparing the first two sessions, when the O did not have knowledge of the VCRs, to the subsequent trials, it is possible to detect any effect due to retention of knowledge of the VCRs.

Table 10 shows that the VCRs do not significantly influence the O's detection accuracy for the accompanying CMM nor do they subsequently affect other CMM tasks for the nonanchored trials. However, it is necessary to determine if the presence of an anchor alters this conclusion. Table 11 shows that the VCRs do not significantly influence the accompanied anchored CMM nor does knowledge of the VCR later affect other CMM tasks.

Table 10

Carry-over Effects I

	Nonanchored				
	No Knowledge	Accompanied		Unaccompanied	
Os	A	C	I	E	K
1. B.W.	6752	5610	5609	6194	6591
Rank	5	1.5	1.5	3	4
2. Y.B.	6142	6711	7630	6305	7005
Rank	1	3	5	2	4
3. L.S.	8334	8097	6340	8106	6825
Rank	5	3.5	1	3.5	2
4. M.R.	7901	7124	7825	7845	7277
Rank	5	1	3.5	3.5	2
5. D.P.	7413	6560	5977	7708	6270
Rank	4	3	1	5	2
6. B.G.	6074	7138	6977	5813	6197
Rank	2	5	4	1	3
7. J.F.	7677	9318	9846	9242	9334
Rank	1	3.5	5	2	3.5
8. A.R.	6315	5893	5308	6292	5640
Rank	4.5	3	1	4.5	2
Rj	27.5	23.5	22.0	24.5	22.5

$\chi_r^2 = 0.90 \qquad p > 0.90$

Table 11

Carry-over Effects II

	Anchored				
	No Knowledge	Accompanied		Knowledgable	
Os	B	F	L	H	N
1. B.W.	6785	7845	8168	7310	6281
Rank	2	4	5	3	1
2. Y.B.	6945	6534	9172	5742	9280
Rank	3	2	4	1	5
3. L.S.	8726	8416	8779	7850	9183
Rank	3.5	2	3.5	1	5
4. M.R.	8995	7693	6615	7223	7264
Rank	5	4	1	2.5	2.5
5. D.P.	7747	7138	6537	5667	5742
Rank	5	4	3	1	2
6. B.G.	7407	6882	7142	7494	7062
Rank	4	1	3	5	2
7. J.F.	9046	9608	9554	9527	9800
Rank	1	4	2.5	2.5	5
8. A.R.	6316	7854	5855	6225	4758
Rank	4	5	2	3	1
Rj	27.5	26.0	24.0	19.0	23.5

$X_r^2 = 1.05 \qquad p > 0.90$

Interaction Effects

So far only the presence of an auditory anchor has had any effect upon the Os' detection accuracy. Practice has no effect, nor is there any residual transfer. Also, the VCRs have no effect upon the Os' performance, nor is there a carry-over effect of the VCR strategy. Only the auditory anchor produced a significant improvement in the CMM and VCR, except when CMM is unaccompanied by verbal ratings. Conceivably, there is an interaction between the unaccompanied CMM and some other parameter. The parametric analysis of variance could assess any interaction effect. In order to reduce the variance of scores for each O, the Ags for similar conditions were averaged. The first half of the experiment was repeated with erroneous feedback, but the experimenter's erroneous feedback had no affect upon the Os' performance. Therefore, the scores from the first half of the experiment were combined with the scores of the second half in order to reduce each O's variance, Tables 5 and 6 (p.80).

In order to reduce the variance among the different Os an inverse sine transformation was calculated for all scores (Ags). An inverse sine transformation was chosen since each O's scores had a different mathematical set or a different binomial population.

Table 12

Interaction Effects

Conditions					
No Knowledge of VCR		Accompanied by VCR		Unaccompanied by VCR	
Anchor	Nonanchor	Anchor	Nonanchor	Anchor	Nonanchor
B	A	F + L	C + I	H + N	E + K

Source of Variation	Sum of Squares	d.f.	Mean Square	F	P
VCR	0.214	2	0.107	0.91	
Anchor	1.265	1	1.265	10.73	0.001
Interaction	0.156	2	0.078	0.07	
Within Treatments	4.848	41	0.118		

There is no interaction effect. Only the anchor is an influencing factor. (The analysis of variance only confirms the results of the nonparametric tests). The unaccompanied CMM is not affected by the VCR nor by the auditory anchor. Post experimental inquiry of the Os supports the conclusion that they did not use the verbal rating scale for their unaccompanied CMM task. The Os maintain that they used a dichotomous system; either the EDS is present or absent, and not, e.g., sixty per cent certain the EDS being present. Possibly, on occasion, the Os do use the verbal rating scale and have subsequently confounded the results.

Discussion

CMM, analyzed by signal detection theory, is an indicator as to how humans process auditory signals that are not affected by: (1) practice, (2) the experimenter, (3) sequence of presentation, and (4) carry-over effects.

There appears to be a partial resolution as to the kinds of difficulties humans have in processing auditory stimuli. The O appears to have the most difficulty diagnosing the auditory stimuli rather than integrating the correctly perceived auditory information. If the O had difficulty integrating the auditory information, the knowledge and use of the VCRs should have eliminated the difference between VCR and the accompanying CMM, i.e., the better detection accuracy of the VCR should have affected the accompanying CMM, if the O has difficulty integrating the auditory information. However, this does not happen. Therefore, the O does not appear to have difficulty integrating auditory information. The difficulty seems to be that the O does not assign the correct value to the auditory signals, consequently the O's decision is based upon a faulty diagnosis of the auditory stimuli.

Whenever an auditory anchor is present the O's performance increases to the same level of accuracy as the VCRs, Fig. 4 (p. 95). Since the auditory anchor is not a mechanism that brings together or combines information, rather, the anchor seems to aid the O's diagnosis of the auditory stimuli. The auditory anchor is the only condition that had an effect on the Os' performance. The means by which the anchor aids diagnosis of auditory signals is investigated in experiment 2 (below).

When an auditory anchor is present, there is also a significant improvement in the VCR. This observation recurs in later experiments. Consequently, an attempted explanation will be deferred until all the evidence has been given.

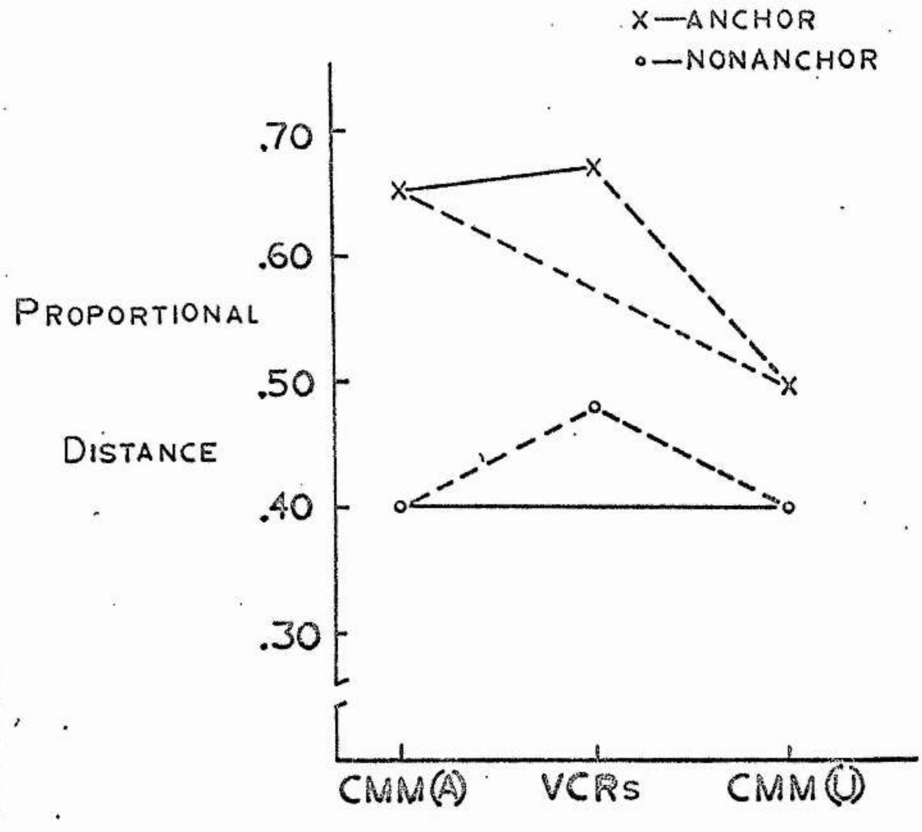


Fig. 4. The proportional distance between CMM conditions: (A) CMM accompanied by VCRs, (V) CMM unaccompanied by any other response, (x) anchored, and (.) unanchored. Proportional distances are determined for each O by assigning zero to his lowest Ag, one to the highest Ag and proportions to intermediate values of Ag. For example, B.W. Anchored: CMM (A) is sessions F+L equals 16013, proportion is 0.87; VCR is sessions G+M equals 16740, proportion is 1.00; CMM(U) is sessions H+N equal 13691, proportion is 0.45. Nonanchor: CMM(A) is sessions C+I equals 11219, proportion is 0.00; VCR is sessions D+J equals 12445, proportion is 0.22; CMM(U) is sessions E+K equals 12785, proportion is 0.28. All Os are treated similarly and a mean is determined for each group. Mean values across all Os are plotted. Broken lines indicated a significant difference, and continuous lines indicate no significant difference. There is a significant difference between anchored and unanchored conditions, except for CMM (U).

Summary

Experiment one has demonstrated the following:

1. There is no practice effect.
2. There is no experimenter effect.
3. There is no residual effect.
4. The presence of an auditory anchor significantly improves the detection accuracy of the CMM and VCRs.
5. The VCRs can detect the presences of signal from noise better than the accompanying CMM. This difference is eradicated when an auditory anchor point is present by bringing the level of performance of the CMM condition up to that of the VCR condition.
6. There is no carry-over effect of the VCRs to other unaccompanied CMM tasks.

Chapter 5

Experiment Two

Introduction

One of the most immediate questions arising from the previous experiment is: why is the presence of an auditory anchor so critical? Is it possible that the anchor point provides an external memory (pseudomemory) as to the loudness level the O has set for himself? - above which level are represented degrees of confirmation that EDS is present and below which are represented degrees of confidence that only noise is present. It may be that the Os have difficulty diagnosing (assessing) their position on the loudness continuum due to a faulty memory for their cutoff point. Naturally, the symbolic rating scale (VCR) would not have this difficulty. Whenever the anchor point (pseudomemory) is provided, one source of error (wrong selection of the cutoff point) is reduced and thereby performance improves.

Questions arising from this hypothesis are: (1) does the presence of the auditory anchor point affect the VCRs to the same degree as the CMM? (2) does the auditory anchor cause an interaction between the VCRs and CMM?

These questions can be answered by introducing a delay between the O's auditory adjustments (the dependent variable) and his anchor point, Fig. 5.

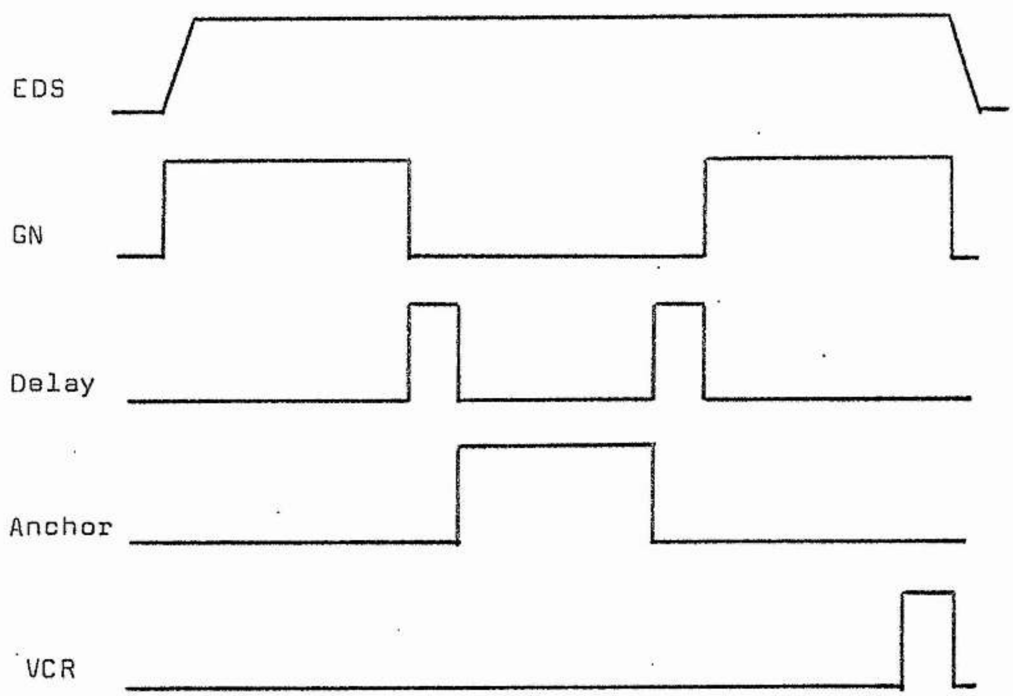


Fig. 5. Sequence of experimental events.

The first condition is: the immediate presentation of the anchor point to determine the O's optimal performance. Other conditions would be the introduction of progressively longer delays between the GN adjustments and the reference point. Adopting the hypothesis that the auditory anchor is serving as a pseudomemory for the O, then one would expect performance (i.e., the O's ability to separate signal from noise as determined by Ag) to be less accurate as the time delay increases. This is because the O needs to retain the auditory cutoff point in his own memory over longer periods of time. If the anchor is providing a pseudomemory for the O's auditory cutoff point then his performance should deteriorate as the delay increases. The absence of auditory anchor point is the last condition causing the O to depend entirely upon his own memory for the GN cutoff point.

Method

Subjects

Four males and three female Os were tested, none reported a history of otologic or neurologic disease.

Apparatus

The apparatus is outlined in the Method chapter (p.62).

Procedure

The procedures are outlined in the Method chapter (p.63) and in Fig. 5.

Experimental Design

After the training session, the Os returned five times and were tested on four interpolated delays between the variable GN and the auditory anchor and one session when no anchor was present. The delay periods were: (1) zero, (2) one second, (3) two seconds, (4) four seconds, and (5) no anchor present. The Os were informed as to their performance after every 35 trials. A session was two hours long. Total experimental time was 84 hours.

Results

Data

ROC curves were constructed for the five delay periods. Then the area under the ROC curve, Ag, was determined. When comparing Ag magnitudes a range of fifty square millimeters was considered a tie due to possible counting errors.

Delay Effects on CMM

Null Hypothesis. H_0: the delays between the dependent variable (GN) and the auditory anchor point will have no affect upon the CMM task. H_1: increases in the length of the delay between the dependent variable and the auditory anchor point will result in a progressive decremental effect upon the O's ability to separate signal plus noise from noise only.

Statistical Test. Because the data, Ag, is composed of more than two related samples and the data is of a nonparametric nature (Banks, 1970) with interval strength, the nonparametric two-way analysis of variance was chosen rather than parametric.

Rejection Region. The region of rejection consists of all values of X_r^2 which are so large that the probability associated with their occurrence under H_0 is equal to or less than $\alpha = 0.05$.

<u>Statistical Conclusion</u>. The area under the ROC curve, Ag, was determined for each delay (0, 1, 2, 4 seconds and no anchor point) and these scores were ranked for each of the seven Os under the five conditions. Scores and ranks are given in Table 13.

Table 13

Delay Effects on CMM

Os	Delays				
	Zero	1 sec.	2 sec.	4 secs.	No Anchor
1. N.M.	6920	7784	5528	5718	5367
Rank	2	1	4	3	5
2. G.M.	6715	5675	6265	6720	6396
Rank	1.5	5	4	1.5	3
3. R.L.	7901	6407	6404	5434	6013
Rank	1	2.5	2.5	5	4
4. R.I.	8255	8568	9093	7352	6788
Rank	3	2	1	4	5
5. C.T.	7482	7474	6852	5795	6489
Rank	1.5	1.5	3	5	4
6. E.G.	8600	6429	7613	7140	5525
Rank	1	4	2	3	5
7. S.L.	7710	7637	6750	7083	5939
Rank	1	2	4	3	5
Rj	11	18	20.5	24.5	31

$X_r^2 = 12.63 \qquad 0.001 > p < 0.01$

Consequently, the null hypothesis, that there is no difference for the conditions, can be rejected with respect to location (mean rank) at the minimum 0.01 level of significance.

For each O, a relative proportion is determined for each of his scores. Zero (0) represents the lowest score while one (1) represents the highest score. Between scores are a proportion of the range. Thus, a delay of one second for N.M. is assigned the value of one since it has the largest Ag of 7784. Similarly, the no anchor condition of 5367 is assigned the value of zero since it is the lowest Ag for N.M. Hence, the four second condition, 5718, is 0.15 of the total range, two second condition is 0.07, the zero condition is 0.64. All the other Os' data are treated in a similar manner and a mean is calculated for each condition. Thereby no one O unduly influences the relative distances between conditions. The relative distances between conditions are averaged over the seven Os and plotted for each delay period, Fig. 6. Results indicate that the auditory memory has a total span of about four seconds and a half life of 1.5 seconds.

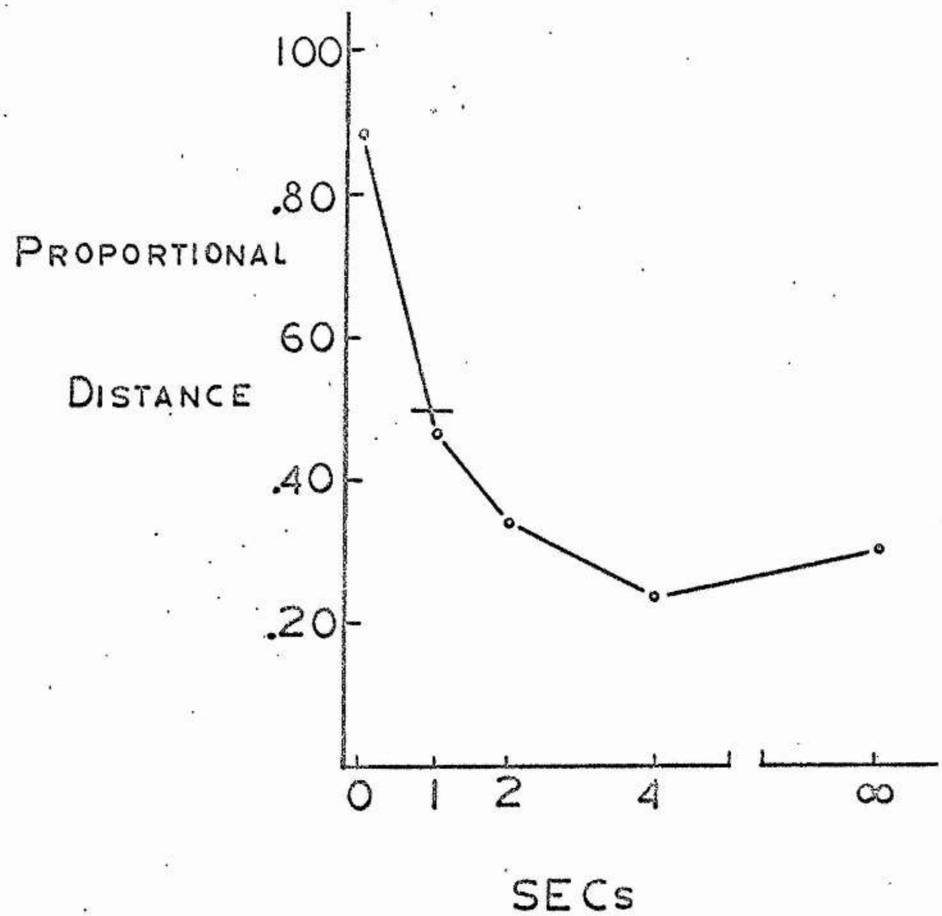


Fig. 6. The relative strength of the auditory memory as a function of time.

Delay Effects on VCRs

Null Hypothesis. H_0: there is no difference between the VCRs for the various delays. That is, O will be able to separate signal plus noise from noise only, as determined by Ag, for each of the five delays with no decremental effect. H_2: with longer delays between the GN and the auditory anchor, the O's VCRs will have a corresponding decrease in detection accuracy.

Statistical Test. The data, Ag, is composed of more than two related samples and the data is non-parametric with an interval measurement and with an extremely small sample size; consequently, a Walsh test was chosen.

Rejection Region. Only the last four Os give VCRs; consequently the sample size is extremely small. The best possible level of significance is $\alpha = 0.062$. Therefore, no definitive answer can be made to the hypothesis. Rather, an indication as to the possible answer will be provided.

Statistical Conclusion. The area under the ROC curve, Ag, was determined for each delay: zero, one, two, four seconds and no anchor, for the VCRs. There was no difference between zero, one and two seconds delay; therefore, the three scores were combined to establish a more representative performance for each O, Table 14.

Table 14

Delay Effects on VCRs

		Delays		
	Os	0, 1, 2 secs.	4 secs.	No Anchor
4.	R.I.	8936	8016	7402
5.	C.T.	7333	5370	7063
6.	E.G.	6836	7739	6307
7.	S.L.	8107	7920	5633

The Walsh test for the difference between the short delays and the no anchor condition gives a probability of 0.062. When the relative distance between the means for each of the delays are plotted, Fig. 7, we find that the verbal memory has an undetermined total time span, but its half life is about four seconds.

Carry-over Effects between VCRs and CMM.

Lastly, is there a carry-over effect between VCR and CMM during the different delay periods? This question has been answered in part in the 1969 study (Hicks, 1969 - see Appendix II). Briefly, when CMM was accompanied by VCR, the performance of O to separate signal from noise only during CMM improved in comparison to CMM unaccompanied by VCR. There is an interaction between VCR and CMM. However, what parameter is being carried-over?

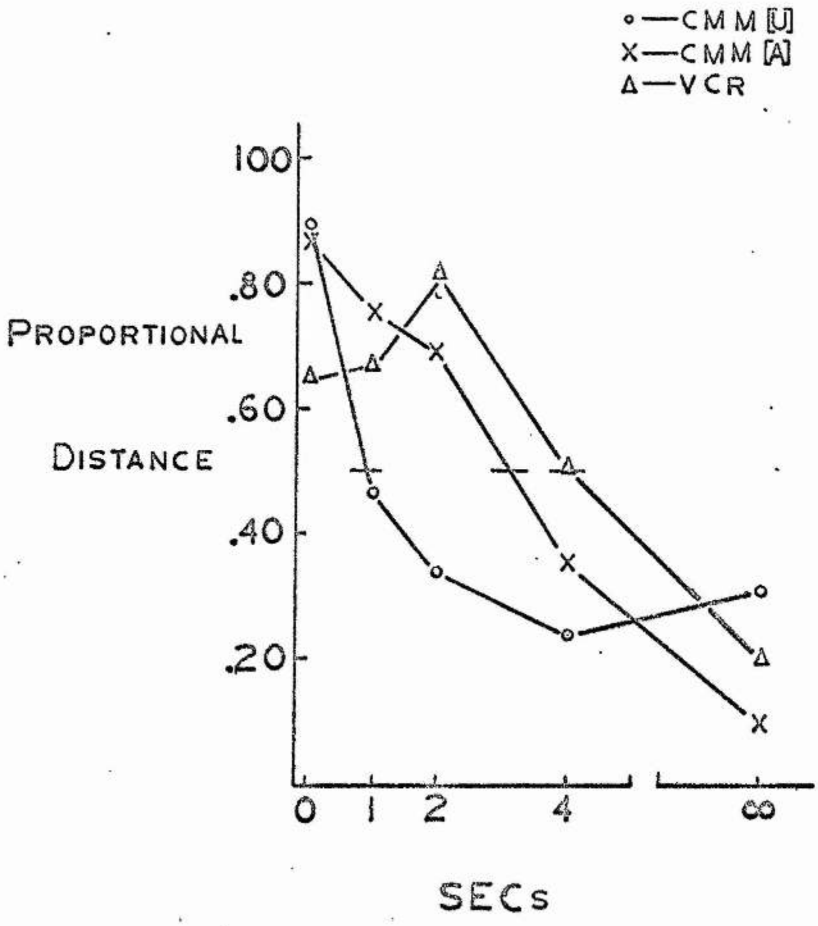


Fig. 7. The relative strength of: (1) CMM [U] unaccompanied by VCR, (2) CMM [A] accompanied by VCR, and (3) VCR as a function of time.

In Fig. 7, there are three functions. The first function is CMM unaccompanied by any other response mode (data from N.M., G.M., and R.L.). The half-life for the auditory memory is about 0.9 of a second. The second function shows the results from Os: R.I., C.T., E.G., and S.L. Their CMM was accompanied by VCR. The half-life for the accompanied auditory memory is about 3.1 seconds. The third function also shows results from the last four Os for the VCR. The VCR half-life is about 4 seconds.

Table 15

Memory half-lives for VCR and CMM

Memory	Half-life
Auditory (Mean)	1.5 seconds
Auditory (Unaccompanied)	0.9 seconds
Auditory (Accompanied by VCR)	3.1 seconds
Verbal	4.0 seconds

The interaction between CMM and VCR may be caused, in part, by a carry-over from the VCR of a more persistent memory trace to the CMM. In other words, the O's intrinsic criterion as to his auditory cutoff point becomes more stable (resistant to decay) when the CMM is accompanied by VCR. Consequently, the O makes fewer wrong decisions as to the loudness level of the GN. The O could be regarded as having an unstable memory for his auditory cutoff point and the presence of VCRs adds persistency to his auditory memory.

Discussion

The auditory memory appears to be an entity that is unaffected by a variety of variables (experiment one) and to possess its own unique parameters. Conceivably there are as many different memories as there are information-response modalities. Each one of the information-response memories has its own parameters, e.g., capacity, retrieval mechanisms, encoding, half-life and interaction with other information-response systems. This explanation would be parsimonious with Miller's (1956) results that the digital memory span is seven plus or minus two digits, while Haber (1970) found that subjects could visually recognize ten thousand different pictures. Simply, there is no grand design that is applicable to all information-response modalities.

Evidence from psycholinguistics lends support to the trend of evidence found in this study. Fillenboun (1966) tested recall of sentential material and found that subjects were more likely to preserve the memory for the gist of a sentence (its semantic content) rather than recall its formal (syntactic) features verbatim. The meaningful, semantic content, is retained while syntactic features tend to decay to a random level after only 27 seconds (Sachs, 1967). "Form which is not relevant to the meaning is normally not retained." Even when sensory information has syntax, language, it rapidly decays. When information lacks conceptual syntax, e.g., simple sensory stimuli, it decays very rapidly. Oversimplified, man's auditory knowledge of the world he lives in is semantically coded and retained. All other forms of information rapidly decay.

Summary

Experiment two has demonstrated the following:

1. When the auditory anchor point is delayed in time there is a progressive but rapid decrement in performance.
2. The decrement of decay for the auditory memory to its half-life level is about 0.9 of a second.
3. The half-life of the verbal memory is about 4.0 seconds.
4. The VCRs interact with the CMM.
5. The interaction causes the half-life of the auditory memory to increase to about 3.1 seconds.

The results of this experiment support the postulate that the anchor point serves as pseudomemory for the O's cutoff point. Without the pseudomemory (anchor point) the O's cutoff point shifts throughout the session thereby causing errors to be made for the CMM. During this time the VCRs remain stable and consequently reflect a greater detection accuracy. When an anchor point (pseudomemory) is available for the CMM, its detection accuracy is equal to the VCRs. However, the O's memory for his cutoff point is remarkably short, about 0.9 of a second. In other words, the O's memory for his auditory cutoff point decays within a second.

Note that the performance for the verbal memory deteriorated when there was a delay of information to the auditory memory. This finding plus the results from the previous and the next experiment will be discussed in chapter six (p. 125).

Chapter 6

Experiment Three

Introduction

The previous experiment demonstrated that information stored in the auditory memory decays relatively rapidly. Auditory memory may share similar properties with verbal short-term memory. Petersen (1963 and 1966) defines verbal short-term memory in terms of forgetting, "The rapid forgetting could be ascribed to the short-term memory (p. 94)." Petersen attributes the rapid forgetting to two factors, "... interference from similar messages and decay (p. 95)." The auditory memory does decay rapidly but is it prone to interference from similar messages?

Method

Subjects

Two male and four female adults were tested, none of them reported a history of otologic or neurologic disease.

Apparatus

The apparatus is outlined in the Method chapter (p. 62).

Procedure

The procedure is outlined in the Method chapter (p. 63) and Fig. 5 (p. 98). The O's performance was maintained at an asymptotic level by offering 0.50 np for each correct response and penalized 0.50 np for each incorrect response. The O was informed as to his performance after every 35 trials. After the training session the Os returned for four more sessions. Each session lasted two hours. Total experimental time was 60 hours.

Experimental Design

An interfering signal (GN) is interpolated between the dependent GN (the variable stimuli) and the anchor (replacing the delay period in Fig. 5). Four different interfering signals were randomly interpolated for a duration of one second, one interfering signal per trial. As before, the auditory anchor is defined as the O's auditory cutoff point for separating signal from noise and operationallydefined as the O's fifty per cent response level. The interfering signals are also GN whose magnitudes are: (1) ten, (2) forty, (3) sixty, and (4) ninety per cent level of responding. These levels were chosen in accordance with Helson's (1947) Adaptation-Level Theory (ALT).

The basic premise underlying ALT is that judgments are made relative to an internalized standard (the AL) which roughly corresponds to the weighted logarithmic mean of the entire series presented in an experimental session. A stimulus, therefore, may be above the AL in a context of lesser stimuli, but be below it when presented subsequently with stimuli of greater strength. Judgments are based upon the comparison of each stimulus with the AL. Helson claims that judgments will differ for the same stimulus in varying contexts. "Adaptation level represents the zero of function, and, since it is always associated with positive values of stimulation, stimuli below as well as <u>above</u> level exert positive effects on behaviour (Helson, 1964 p.62-63)." Furthermore, "intensity of response is a function of distance from, or ratio of stimulation to, prevailing level; The greater the magnitude of the ratio or distance, the steeper is the excitation gradient and the greater is the response (Helson, 1964 p.62-63)." According to ALT the effects of the interfering signals can be predicated. In mathematical terms, the level of behavioural adaptation (A) is defined as a weighted product of the three classes of stimuli: focal (X), background (Y) and residual (R) (Helson, 1959). The anchor is the focal stimulus which is always a constant (50 per cent level of responding). The variable stimulus and any residual (R) is assumed to be fifty per cent due to the effects of randomization. The interference is background (Y). Therefore:

$$\log A_{10} = h \log \bar{X} + i \log Y + j \log R$$

$$= 0.33 \log 50 + 0.33 \log 10 + 0.33 \log 50$$

$A_{10} = 28.98$ (The three classes of stimuli

$A_{40} = 45.61$ are assumed to contribute

$A_{60} = 52.25$ equal effects.)

$A_{90} = 59.68$

Results

Data

ROC curves were constructed for the four different kinds of interference. The areasunder the ROC curves (Ags) were then determined, Table 16. Plus or minus fifty square millimeters is considered an Ag tie due to possible counting errors.

Contextual Effects on Sensitivity

Null Hypothesis. H_0: the four interpolated GN interfering signals will not systematically affect the O's ability to separate signal from noise. H_1: Os' performance (Ag) will be detrimentally affected as the magnitude of the interfering signal increases.

Statistical Test. Each O was assessed during four different conditions (related samples) and because Ag is nonparametric (Banks, 1970), the nonparametric Friedman two-way analysis of variance was chosen.

Rejection Region. The region of rejection consists of all values of X_r^2 which are so large that the probability associated with their occurrence under Ag is equal to or less than $\alpha = 0.05$.

Statistical Conclusion. The randomly presented interfering signals were arranged according to the four magnitudes. There are no significant contextual effects for CMM nor for the VCRs, Tables 16 and 17 respectively.

Table 16

CMM Context Effects

	Level of Interference			
Observers	10%	40%	60%	90%
1. B.H.	6941	7493	7200	6931
Rank	3.5	1	2	3.5
2. D.L.	6437	7579	6110	6364
Rank	2	1	4	3
3. C.L.	7348	7807	7384	7549
Rank	3.5	1	3.5	2
4. D.R.	6439	5855	6336	6255
Rank	1	4	2	3
5. H.A.	6762	6591	6019	6926
Rank	2	3	4	1
6. M.G.	6152	6741	6635	6394
Rank	4	1	2	3
Rj	16	11	17.5	15.5

$X_r^2 = 2.35 \qquad p = 0.430$

Table 17

VCR Context Effects

	Level of Interference			
Observers	10%	40%	60%	90%
1. B.H.	7996	8246	8672	8244
Rank	4	2.5	1	2.5
2. D.L.	7354	8099	7455	7601
Rank	4	1	3	2
3. C.L.	8329	8428	7948	7820
Rank	2	1	3	4
4. D.R.	6699	6460	6723	6644
Rank	2.5	4	1	2.5
5. H.A.	6870	6697	6734	7085
Rank	2	4	3	1
6. M.G.	6158	7759	7432	7466
Rank	4	1	2.5	2.5
Rj	18.5	13.5	13.5	14.5

$X_r^2 = 1.7 \qquad 0.43 > p < 0.57$

Contextual Effects on Base-line Shifts.

Null Hypothesis. Even though the interfering signals do not affect the O's sensitivity for separating signal from noise, it is possible that the entire response continuum has been shifted and this is not detectable by signal detection theory. H_0: the four interpolated GN interference signals will not systematically shift the Os' cutoff point (see Fig. 1). H_2: the Os' base-line will geometrically shift upward as the magnitude of the interference increases.

Statistical Test. Friedman two-way analysis of variance.

Rejection Region. Alpha is 0.05.

Statistical Conclusion. The randomly presented interfering signals were arranged according to the four magnitudes. Then a point in the response continuum is established which has an equal proportion of false alarms to misses. The absolute magnitude of this point is the data plus or minus a resolution factor. Finer discriminations than the resolution factors would be mathematical artifacts since the meter reading could not be accurately determined within this range. There is no significant auditory base-line shift, Table 18.

Table 18

CMM Base-line Shift

		Context			
Os	Resolution Factor	10%	40%	60%	90%
1. B.H.	± 10	210	220	245	221
Rank		4	2.5	1	2.5
2. D.L.	± 5	171	192	186	184
Rank		4	1	2.5	2.5
3. C.L.	± 10	480	509	475	500
Rank		3.5	1.5	3.5	1.5
4. D.R.	± 10	185	194	201	210
Rank		4	2.5	2.5	1
5. H.A.	± 10	190	180	165	195
Rank		1.5	3	4	1.5
6. M.G.	± 10	207	208	203	210
Rank		2.5	2.5	2.5	2.5
	Rj	19.5	13.0	16.0	11.5

$\chi_r^2 = 3.75 \qquad 0.20 > p < 0.30$

Discussion

One property of auditory memory is shared with the verbal short-term memory. Both memories decay relatively rapidly. Here the similarity appears to end. Auditory memory does not appear to be affected by interference from similar messages. This observation is not unique. Other studies using simple sensory stimuli have shown the same effect. It appears that the results of these studies have been ignored. For example, Corso (1967) discusses ALT at considerable length but does not mention the incompatible findings of Brown (1953) and Davidson (1962). However, both Brown and Davidson chose to explain their results as minimally incompatible with ALT. Possibly Corso did not consider their observations sufficiently relevant to be included.

Brown (1953) observed, in a weight discrimination task, that when Os were asked to pass him a heavy tray between each series of trials it did not seem to act as an anchor in that no contrast occurred. Helson (1964) confirmed Brown's conclusions that a tray may be objectively heavy, but if the size-weight illusion were operating it might be subjectively lighter than the density of the canisters used in weight lifting experiments. Both authors conclude that the stimuli must be objectively and subjectively similar. Contrarily, Tresselt (1965) found that heavy books could produce anchor effects, and von Wright and Mikkoren (1964) observed that, when O was asked to help lift a heavy table this too produced a typical contrast effect.

Davidson (1962) found that an irrelevant anchor was ineffective in altering judgment. His stimuli were rectangles of different size and illumination. When Os were exposed to an anchor which varied in both height and illumination, but O had to judge only one of these attributes, judgment distortions occurred only when the relevant dimension was altered. For example, when variations occurred in the height but the O had to judge illumination no judgment distortions occurred. The results do not support Helson's theory of a pooling background effect.

The question remains: why was there no context effect as predicted by ALT? Os regarded interfering stimuli as irrelevant to their judgments; and consequently they effectively ignored any intruding stimuli. Helson's ALT is not compatible with this finding. Also, ALT predicts, "the greater the magnitude of the ratio or distance, the steeper is the excitation gradient and the greater is the response." The ratios of behavioural adaptation, as previously determined are: (1) 1:1, (2) 1:1.57, (3) 1:1.80, and (4) 1:2.06. The experimental ratios are: (1) 1:1, (2) 1:1.05, (3) 1:0.99, and (4) 1:1.01. (p.114)

The only way in which Helson's equation could be made compatible with the present experimental data is by eliminating factor, i log Y, the background factor.

Furthermore, the Os had the greatest difficulty with interfering signals of a magnitude in close proximity to the anchor rather than to the extremes, Fig. 8. This experiment does not demonstrate a pooling effect of the signals.

ALT confronts other incompatibilities. Ellis (1972) used eight Os to make auditory judgments by, "comparing two objectively equal stimuli with anchors preceding, interpolated between, or following the pair. The results suggest that proactive contrast rather than retroactive assimilation accounts for the usual interpolated condition."

Fig. 8 shows that CMM and the VCRs follow a similar pattern. A Spearman Rank Correlation Coefficient was calculated to determine the degree of association between CMM and VCRs across the four levels of interference. With only four categories the correlations must be perfect to reach a significant level. The trend itself is noteworthy (see Table 19) and offers one added bit of information that will be discussed in the next chapter.

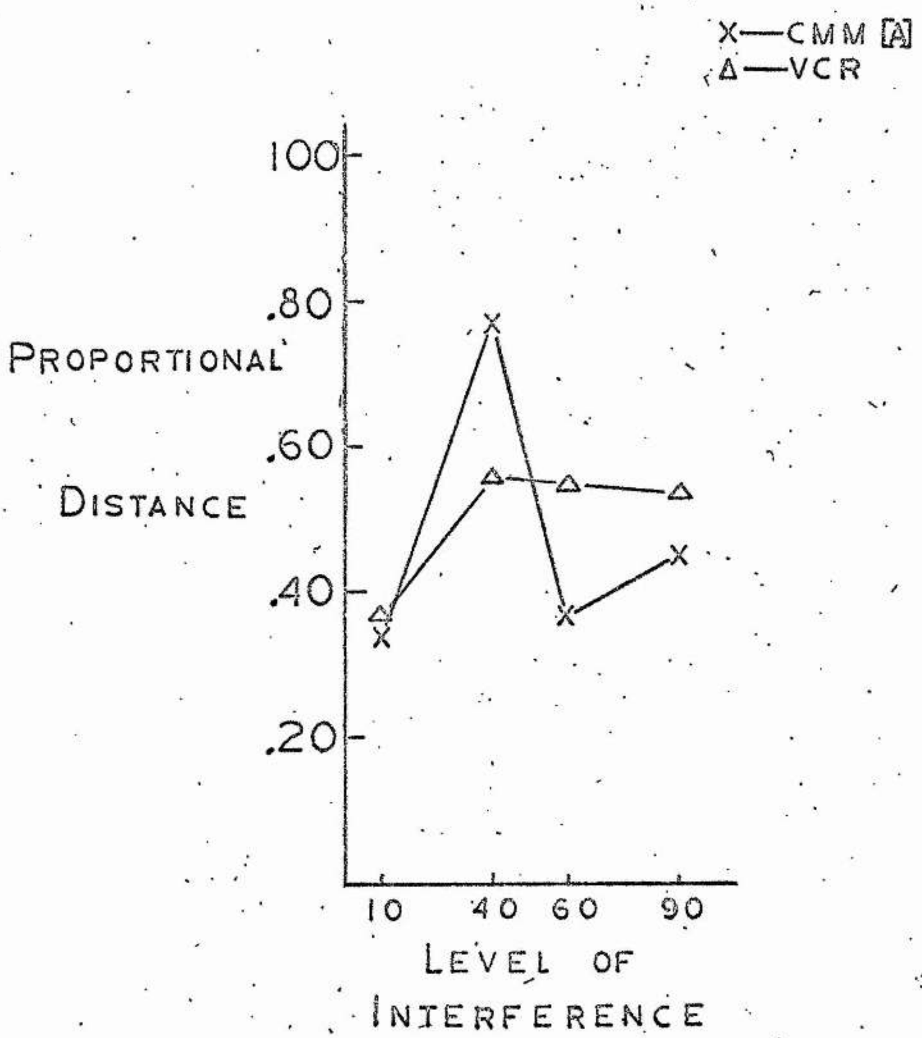


Fig. 8. Contextual effects on CMM.

Table 19

Spearman Rank

Correlation Coefficient

Observers	r_s
B.H.	0.48
D.L.	0.40
C.L.	0.32
D.R.	0.74
H.A.	0.80
M.G.	0.95
Mean	0.60

Summary

Experiment three has demonstrated the following:

1. When four different magnitudes of interfering signals are interpolated between the manipulated GN and its anchor, the interfering signals cause neither a significant change in the Os' sensitivity nor a shift in the response continuum. The results do not support Helson's ALT.
2. The VCRs that accompany the above CMM also demonstrate no significant change for the four different interpolated signals.

3. Where contextual effects do occur, the interfering signals adjacent to the anchor cause the greatest difficulty. Again the results do not support Helson's ALT.

4. There is a nonsignificant positive correlation between the CMM and the VCRs.

Chapter 7

Discussion

The purpose of this chapter is to review the factors of auditory information processing manifested in this study. Based upon the evidence a cybernetic model has been formulated. Subsequently, each component in the system will be delineated in relationship to prevailing evidence.

Review

The previous experiments have demonstrated the following:

1. CMM as an indicator of how humans process auditory information is apparently unaffected by practice effects, carry-over effects, residual transfer effects and experimenter effects.
2. The Os have more difficulty diagnosing (recognising the value of the information) than integrating the auditory information.
3. The VCRs can separate signal plus noise from noise only, better than CMM.

4. When an auditory anchor is available for the CMM, the CMM is as accurate a response mode as the VCRs.
5. The presence of the auditory anchor not only improves the detection of signal from noise for the CMM but also improves the detection accuracy for the VCRs.
6. When a delay period is interpolated between the CMM and the auditory anchor, the detection of signal from noise is progressively impaired as the delay period increases.
7. Consequently, the half-life of the auditory memory when unaccompanied by the VCRs is less than one second. When the CMM is accompanied by the VCRs the half-life of the auditory memory increases to about three seconds. Therefore, the VCRs retard the decay of the auditory memory and make the memory of the auditory signal more persistent than when the CMM is unaccompanied by the verbal rating task. Thus, VCR adds persistency to the auditory memory.

8. The detection of signal from noise for the VCR also decreases as the interpolated auditory delay becomes progressively longer. The half-life for the VCRs is about four seconds.
9. When interfering signals are interpolated between the CMM and the auditory anchor, they have no affect upon detection reliability.
10. There is a positive correlation between the O's CMM and his VCRs response modes.

Single-Channel Processor

Three findings, one from each experiment, have not been discussed. In experiment one, an auditory anchor improved performance, including the VCRs. Why should an auditory anchor improve the symbolic processing of the VCRs? In experiment two, when a progressively longer delay was introduced between the manipulated GN and the auditory anchor, CMM detection was correspondingly impaired, but the accompanying VCRs were also impaired. Why should a delay interval in the auditory system affect VCRs? In experiment three, there was a positive correlation between performance in the CMM and the VCR. One explanation accounts for all three findings, i.e., that auditory information passes through a single-channel processor (Townsend, 1971). VCRs are dependent upon the processing of the auditory information. (A VCR feedback loop also exists but will be discussed later.) Hence, if auditory processing improves so does the VCR, as in experiment one. Conversely, if auditory processing is impaired, the VCR is also impaired, as in experiment two. Processing of information occurs in stages (i.e. serially). Consequently, successive operations are dependent upon the completion of previous stages. This interpretation agrees with other theories of information processing.

Broadbent (1958 and 1971) regards the conscious information processing capabilities of the central nervous system as functioning as a single channel processor. Broadbent's conclusion was reached by analysing the limited transmission rate of information through a verbal, symbolic, recognition or recall system. Such a limit is labelled the information processing "capacity" of the channel. Even though the present paper does not assess "capacity", it gives an experimental attempt to analyse how humans function in terms of the flow of information within the human being.

The topic of a single-channel processor reawakens a classic and still unsolved problem: whether attention can be truly divided between two tasks, or whether it alternates rapidly between one and the other (Woodworth and Schlosberg, 1954). Some work (Mowbray, 1954) has been done in the area of interaction of two simultaneous tasks which is of importance here, since the Os performed both CMM and VCR within the same trial. However, the Os first performed the CMM task and then the VCR task - serial tasks, whereas most studies on divided attention have employed simultaneous tasks - parallel tasks.

Mowbray's (1954) subjects were required to report on passages of letters, digits or prose presented either visually or aurally. The subjects could not adequately function with two different streams of information at the same time, one presented to the ear and the other to the eye. "The effects seemed clearly to be the result of an overloading of some central mechanism, and it is reasonable to suppose that the impairment was due to the single channel being captured by data from one task at a time, to the exclusion of data from the other (Welford, 1968, p.132)."

Assuming a single-channel processor, the effect of two tasks is that the primary task, when given alone, does not totally occupy the single channel. There is spare capacity into which the secondary task can, within limits, be fitted. "Performance is impaired when this spare capacity is insufficient .... the problem becomes essentially one of queueing by signals from the two tasks (Welford, 1968, p.134)."

Welford's conclusions are based upon Mowbray's study where the secondary task .. added to a primary task and the resulting performance is impaired. But the results of Brown (1957) and Conrad (1956) on the effects of pacing raise the question as to whether capacity increases under pressure of speed. For example, heart rate regularity increases with the load imposed by a second task, associated with an apparent increase in channel capacity (Kalsbeek and et al., 1964 and 1967).

So far no one has observed an augmentation of the primary task (CMM) by the introduction of a secondary task (VCR). The augmentation of the primary task is presumably due to the secondary task (VCR) interacting with the memory of the primary task (CMM), thereby causing the auditory memory to be more persistent. The interaction appears to be a negative feedback path from the VCR to sensory memory, thereby making the auditory memory more persistent against decay. However, the cited studies used a parallel experimenal task whereas in this investigation a serial task was used.

Cybernetic Model

The simplest cybernetic problem is the "direct" problem, where the input, the laws, and the properties are given and the problem is to predict the output. The "converse" problem is one sort of problem encountered by physicians where the law, properties and output are given and the problem is then to determine input. The "inverse" problem is when the input, law and output are given and the aim is to determine values for the system properties. The final type of problem is one in which, given only the input and output one is then asked to determine the law and properties of the system. "This inductive or 'black box' problem is the most difficult of all and provides the basis for the solution of the others. It is the problem faced by the scientist (Grodins, 1963, p.2)."

The purpose of this section is to design a signal flowgraph of auditory information as it is processed by the O. The reason for using a signal flowgraph form is that it provides a "degree of insight into system behaviour, far exceeding that obtained by mere algebraic manipulations (Porter, 1969, p.93)." Of equal importance is the broad conceptual perspective as to "how this human system manages to be self-stabilizing in the presence of a multiplicity of disturbances of all kinds is far beyond the present status of control theory to explain (Porter, 1969, p.123-4)."

Fig. 1 shows that the Os' environment and task never changes, and that only the Os' access to auxiliary information is manipulated. Experiment three demonstrated that in the particular situation, the auditory memory for a specific stimulus magnitude was not susceptible to interference from messages of a similar nature. Consequently, in this situation, there must be a filter in the system that regulates the types of information to enter other components, e.g., memory. The filter must be one of the first components in the system otherwise interference would have an effect, which it does not. The filter is probably capable of being programmed, or set, by the O according to his understanding of the experimenter's instructions.

The decision-making apparatus adjusts the GN louder or softer in comparison to some predetermined level. This predetermined level is maintained in memory. Experiment one demonstrated that the decision-making apparatus was making errors in diagnosing the information. The diagnostic error was traced to a memory where the auditory signals decay very rapidly, as in experiment two.

Experiment two also demonstrated that when the O performed the VCR task the cognitive process provides feedback to the auditory memory which retards its decay. Fig. 9 shows the complete signal flowgraph. In the flowgraph the O's environment consists of the EDS and the variable GN. The EDS is always in one of two states - signal or noise only. Upon reception, the GN input is immediately filtered, allowing the passage of only those components of the message which are considered relevant to the task situation. Selected GN components then enter into both the decision-making process and into a memory bank for future reference. The decision is transformed into a response by the adjustment of the loudness level of the GN. The decision-making process is recycled during the trial. For example, if the O changes his decision as to the presence of the EDS or its subjective magnitude, this decision is only one of three factors which may account for an adjustment in the loudness of the GN. The other two factors are: (1) the loudness of the incoming relevant GN, and (2) the memory of the auditory cutoff point. Whenever the VCRs are an added task, the performance of this task occurs after the auditory signal has been processed, but the VCR also provides feedback to the auditory memory resulting in an increased stability against its decay.

Subsequent sections will discuss the system's components, namely the auditory memory and its filter, in detail.

Auditory Memory

Neisser (1967) infers a short-term auditory memory (labelled echoic memory) from the analysis of speech perception. "Since the auditory input is always extended over time, some kind of transient memory must preserve it long enough for the processes of speech perception to operate. As long as the 'echoic' memory lasts, the listener can select portions of its contents for special attention (p.199)." Neisser bases his hypothesis on the notion of analysis-by-synthesis interpretation of speech perception. This notion assumes the existence of a simple stimulus-sample-hole mechanism which compares other templates from memory until one approximately fits the sample, "... The listener's preliminary speech analysis may pick out a few distinctive features or

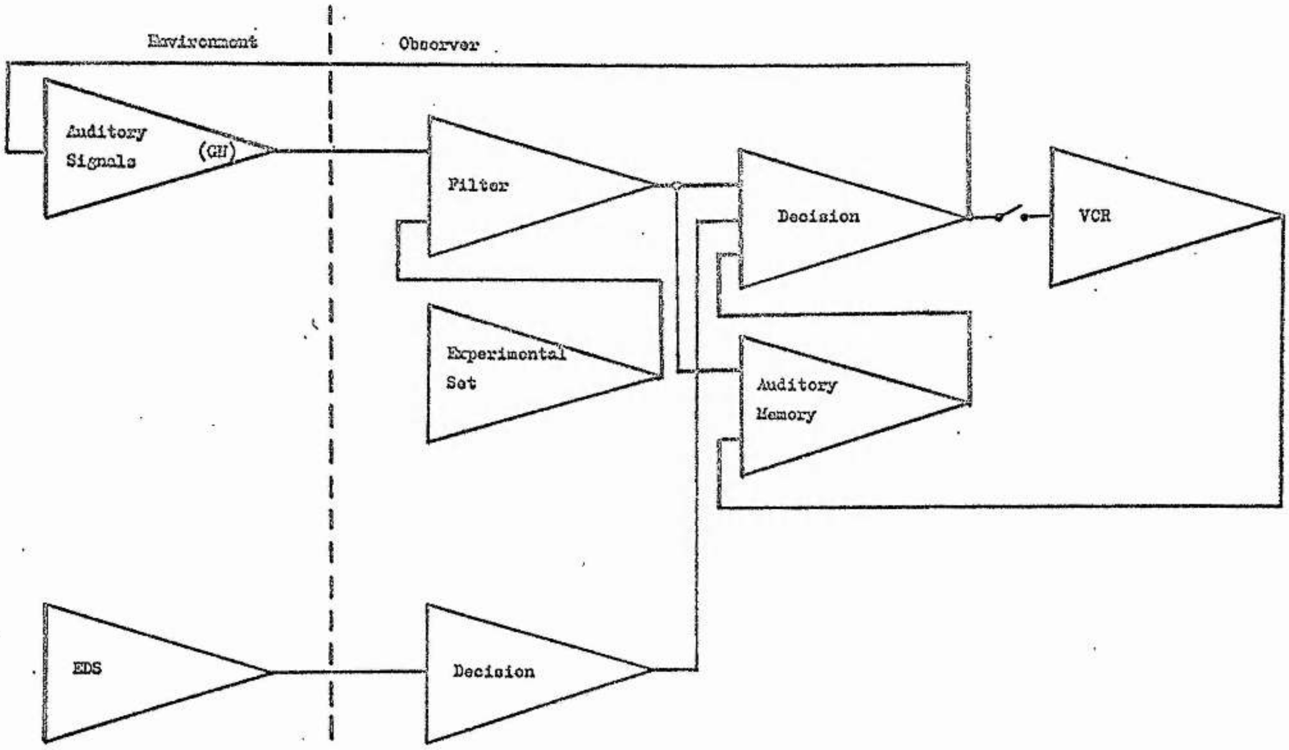


Fig. 9. Signal flowgraph.

syllables which suggest a tentative answer; various related words are then synthesized until one of them fits (p.196)." From this assumption Neisser fabricates echoic memory. "Auditory information is always spread out in time; no single millisecond contains enough information to be very useful. If information were discarded as soon as it arrived, hearing would be all but impossible. Therefore, we must assume that some 'buffer' some medium for temporary storage is available in the auditory cognitive system (p.199)" - echoic memory. Neisser's echoic memory corresponds to what William James (1890, p.643) called "primary memory" but is also similar to "iconic" storage; both terms represent preliminary and transient storage mechanism for incoming information. However, Neisser makes no statement regarding the exact duration of echoic memory.

Perhaps the most direct attempt to measure the duration of echoic memory was made by Guttman and Julesz (1963). A computer blended repetitive segments of white noise in order to test whether the subject would observe the repetition. Repetitive cycles of a second or less were noticed by the subject while repetitive cycles longer than one second were not noticed.

The decay of echoic memory was also measured by Pollack (1959). The message was one of 31 alternative words presented at a fixed signal-to-noise ratio. After delays of one, two, four, eight and sixteen seconds the number of alternatives was reduced to two by giving the subject a pair of words to choose. Performance levelled off after about four seconds.

Eriksen and Johnson (1964) had subjects read a novel and on occasion a tone was presented. After a delay period the lights went out and the subject was queried as to the presence of the tone. The fifty per cent detection level was reached after a delay of 3.5 seconds.

Fraisse (1956 and 1963) in extensive studies of rhythmic structure reports that the intertap interval of the rhythm seems to disappear entirely when the taps are about two seconds apart.

A. Treisman (1964) makes a distinction between segmented and unsegmented material in echoic storage. Her subjects did not expect two messages presented to them to be the same. They were told that the one was irrelevant and only a distraction to be ignored. In successive trials, the time lag between the two messages was systematically reduced from 6 seconds to zero. At some point, every subject noticed that the two messages were identical. When the shadowed message preceded the irrelevant one, the average lag at which identity was noticed was 4.5 seconds. When the irrelevant message was leading, it was only 1.4 seconds. Treisman postulated that the two values represented two different kinds of memory. Echoic storage for unsegmented and unattended material lasts only one or two seconds, while segmented memory survives much longer.

M. Treisman and Howarth (1959) presented a very low intensity tone on a random schedule. On randomly selected trials a warning stimulus followed the tone after a fixed interval. The subject had to report if a tone had preceded the warning stimulus. In this way they showed that an uncoded sensory input could be retained for 0.5 to 1 second.

Massaro (1970 and 1971) has presented evidence for an auditory image which persists for a short time after a tone has been presented. The subjects were asked to classify the pitch of a 20 msec test tone as high or low, and it was found that the subjects' performance was impaired by a preceding masking tone at an interstimulus interval up to about 250 msec. Unfortunately, these results have an alternative explanation which does not assume sensory storage, namely that the masking tone adds variance to the judgmental processes at an early vulnerable period.

M. Treisman and Rostron (1972) attempted to test the hypothesis of echoic memory by adapting Sperling's visual procedure to audition. In this experiment the subjects were seated opposite three loudspeakers. Stimulus one consisted of a set of three simultaneously presented tones from a possible six. After a delay interval, an independent stimulus two set was presented. A probe tone, presented after the second set, from a fourth speaker was one of the six tones. The subjects had to report in which set or sets and through which speaker(s) similar tones had been delivered. A delay interval of 0, 400, 800, or 1600 msec was interpolated between the offset of set two and the onset of the probe. The results obtained are analysed in terms of signal detectability. The authors conclude there is an echoic memory whose contents are lost in about one second. However, as the authors suggest, the six frequencies are very easy to code verbally. Therefore, their results could be contaminated by verbal short-term memory effects.

Table 20 is a summary of the studies attempting to assess the duration of the auditory (echoic) memory. The mean duration of auditory (echoic) memory for all the studies is 1.5 seconds, ranging between 0.25 to 4 seconds. Experiment two in this paper determined that the half-life of the auditory (echoic) memory was under one second and reached an asymptotic level after 4 seconds, see Fig. 7.

Table 20

Studies on Auditory (Echoic) Memory

Investigators	Material	Duration	Measurement
1. Suttman & Julesy (1963)	GN	length 1 sec.	Per cent correct
2. Pollack (1959)	Words	asymptotic level 4 secs.	Per cent correct
3. Eriksen & Johnson (1964)	Tone	half-life 3.5 secs.	Per cent correct
4. A. Treisman (1964)	Vocal (unsegmented)	length 1.4 secs.	Time
	(segmented)	length 4.5 secs.	Time
5. M. Treisman & Howarth (1959)	Tone	length 0.5-1 sec.	Signal Detection
6. Massaro (1970-71)	Tone	length 250 msec.	Time
7. Fraisse (1956,63)	Tapping Rhythm	length 2 secs.	Time
8. M. Treisman & Rostron (1972)	Tones	length 1 sec.	Signal Detection

Auditory (echoic) memory would appear to have implications for other memory mechanisms and their related theories. The operational definition of verbal, symbolic short-term memory (STM) is rapid forgetting. There are two antagonistic theories as to the cause of rapid forgetting in STM: (1) Decay theories assume that the contents of STM disappear spontaneously, unless the information is transferred to long-term memory before the period of decay runs out (Broadbent, 1971, p.10), and (2) Strength theories (Wickelgren and Norman, 1956) provide a mathematical description of the displacement of contents in STM. In other words, the contents of STM are pushed out by incoming information.

Both theories could be assessing STM only, but the possibility also exists that different experimental procedures could, to varying degrees, involve auditory (echoic) memory as well. Hence, the memory seems to disappear spontaneously, if the experimental procedure was partially measuring auditory (echoic) memory. However, if the experimental procedure was minimally involved with the auditory memory the STM contents seem to be displaced. The third possibility is that both theories assess STM and/or its interaction with the auditory (echoic) memory.

Filter

The term filter has many overlapping meanings and sometimes contradictory interpretations. Possibly, experiment three might provide some useful information as to alternative selective mechanisms. In this section, I would like to speculate as to what this mechanism might be.

Broadbent (1971) assumes that the hypothetical filter can be "tuned" by the O to any one of a large number of "channels". The filter will only pass information from the particular channel to which it is tuned. Broadbent feels that responses to several channels simultaneously are possible when the rate of information flow is low. Broadbent's filter operates by selecting those stimulus events which possess some common feature and passing on all other features of those events to the limited capacity system for analysis. This hypothetical filter was developed from the analysis of symbolic processing. However, Broadbent's approach has a good deal in common with the one adopted here; in fact, his phrase "the flow of information in the organism" sums up Neisser's definition of cognitive psychology and the underlying goal of this paper. I also share Neisser's scepticism of Broadbent's emphasis on the value of information measurement. "He (Broadbent) argues that the cognitive mechanism must have a finite informational capacity - in terms of bits per second - and that filtering mechanisms are needed if their capacity is not to be overloaded. This is surely true in some sense but it does not help us to understand the mechanisms in question (filter). One might as well say that the heart, which pumps only about 100 cc of blood per stroke, has limited capacity compared with a fire engine. This would also be true, but by itself would be of little help in understanding the physiology and 'hemodynamics' of the heart (Neisser, 1967, p.208)." Perhaps it is for this reason that Broadbent's latest book, 1971, has emphasised flow charts rather than bits,and probabilistic functionalism rather than determinism.

Broadbent's 1971 book shares a basic philosophical approach with this paper. His approach in 1958 was deterministic, while his first 1971 modification (p.12) was to probabilistic functionalism. Statistically this approach considers: (1) stimuli as populations, Brunswik, 1955; (2) neurons as populations, Crozier, 1940; and (3) responses as populations, Thurstone, 1927. Hence, Broadbent considers stimuli "not determinated information, but rather 'evidence' about the outside world (1971, p.12)." "Brunswik stressed that even very good cues carry only probabilistic information about the distal objects (Sjöberg, 1971, p.31)."

Naturally probabilistic stimuli imply selective perceptions. Man faces a large mass of varied information which is impossible to cope with in its entirety; consequently, he tends to pick out some elements from it. During the 1950s a number of experiments were performed on selective perception in hearing and it was from these studies that the concept of filtering was developed.

Broadbent (1958 and 1971) had postulated a "filter" between the sense-organ and the central mechanisms responsible for identification, which can block off signals so as to pass only those with certain physical characteristics or those from a particular sense organ (Fig. 10). This postulate finds support in the present study, but Broadbent's description of the filter's selectivity is not extensive enough to account for the implications of the present results. The interfering signals in this case had the same physical characteristics as the message as well as impinging upon the same sense organ. But the O was still able to filter out any signal he deemed irrelevant (conditional upon his sensory capability to determine which segment of the message was irrelevant). In experiment three yellow illumination occurred when the interfering signal was presented. The yellow light identified that segment of the message that was irrelevant. If the yellow light had not been presented the O would have probably identified transitions in auditory loudness, or serial classifications, or both. Welford (1968) states, "... it is not enough to postulate a filter acting only on the input from the various sense organs and capable of discriminating against simple sensory categories .... there must be some mechanism facilitating or inhibiting categories of identification (p.102)."

This is probably true when considering symbolic processing, but very effective filtering is accomplished before the memory component. Consequently, we have been forced to develop two filters. One filter would perhaps act on the input to the sense organs (probably governed by efferent selectivity) and a second filter would determine what enters into symbolic short term memory after some symbolic processing has occurred. Here we are concerned only with the former filter.

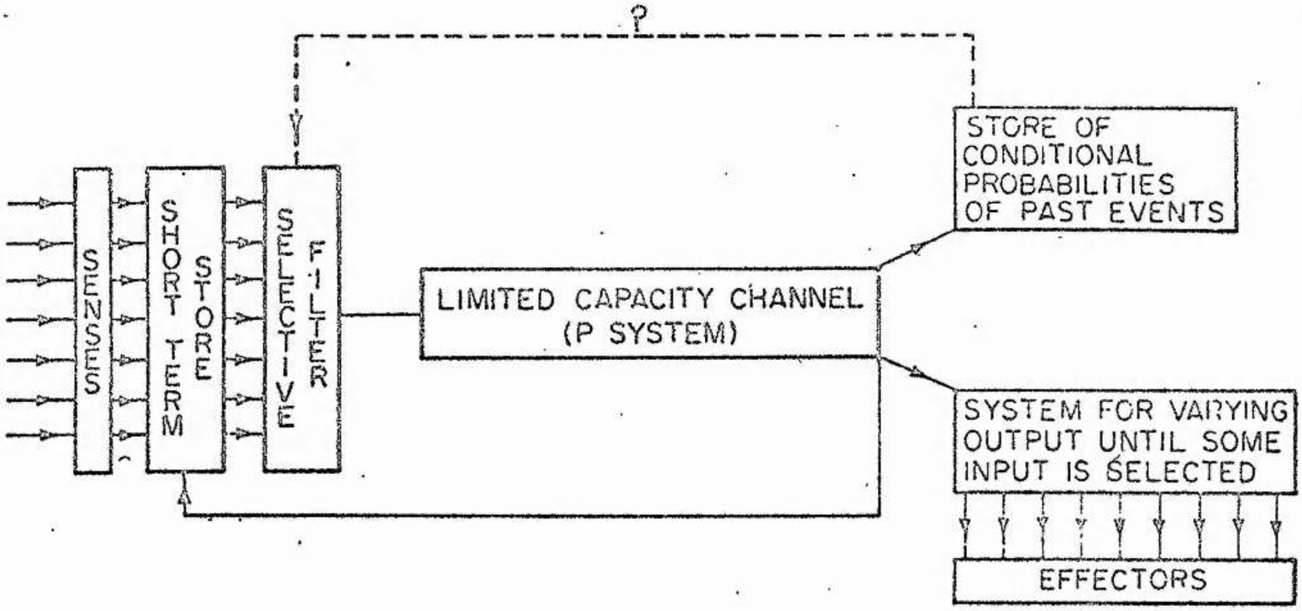


Fig. 10. A diagram of the flow of information within the nervous system, as conceived by Broadbent (1958 and 1971).

This investigation helps to bridge the gap between sensory perception and information processing. The discussion section of experiment three has already demonstrated the inadequacies of Helson's adaptation level theory to account for the experimental findings. Helson states "even the simplest sensory experiences are more or less complex, containing focal, contextual, and organic components. The pooled effect of these three classes of stimuli determines the adjustment or adaptation level underlying all forms of behaviour (1964, p.37)." Experiment three found that the Os are capable of rejecting any stimulus that is irrelevant to their decision-making.

The sensory filter precedes auditory (echoic) memory. The sequence of events in experiment three were: (1) seven seconds of variable GN indicated by a green light, (2) one second of interfering GN indicated by a yellow light, (3) seven seconds for the auditory anchor indicated by a red light, (4) repeated interference, and (5) seven more seconds of variable GN. Also,experiment two demonstrated that the half-life of the auditory (echoic) memory is less than one second. If an interfering signal entered into auditory memory it should have a measurable effect. Since this does not occur some mechanism must block its entry. Even though Welford uses different terms to summarise his chapter, which is based mainly on data from verbal experiments, his general conclusion is markedly similar to that indicated by the results of experiment three. "Looking at perceptual identification in broader perspective, we can think of each object seen or event which occurs as preactivating potential identification and responses for other likely objects and events which will, in consequence, when they arrive be reacted to more quickly than if they had occurred in isolation - in common parlance the subject knows what he is looking for and tends to ignore other things (p.104)."

Possible interpretations of the auditory filter involve: (1) selective perception, (2) filter attenuation and, (3) selective attention. None of the headings are separate entities. Broadbent's filter does not account for the ability of names, probable words, and identical meanings in the rejected message to force themselves on the subject's attention; he must be listening to it in some sense. For these reasons both Moray (1959) and Deutsch and Deutsch (1963) find it necessary to assume that all inputs are analysed rather completely, with filtering or selections taking place only subsequent to the analysis. This solution is unsatisfactory (as Neisser, 1967, mentions), because it does not explain why so little of the rejected message makes an impression.

In 1960, A. Treisman suggested a theoretical way out of this difficulty. Her suggestion was that the filter attenuates signals rather than eliminating them and that the weakened signals can still be picked up by specially attuned cognitive systems. Unattended channels are not "switched off", as Broadbent had proposed, but attenuated. Neisser (1967) cannot accept this hypothesis, "surely selective attention is not just a matter of selective attenuation, p.212."

In turn, Neisser suggested his own hypothesis which identifies "two hypothetical stages in the perception of speech. At one level preliminary identification of words and other cognitive units are carried out by a passive filter system .... But this preliminary system does not do the entire job; it is normally supplemented by an active process of analysis-by-synthesis, in which the listener produces 'inner speech' (at some level of abstraction) to match the input. I suggest that <u>this constructive process is itself the mechanism of auditory attention</u>, p.213."

It is not relevant to the main issues considered here to discuss the process of speech perception. But, as previously stated, the author can agree with Neisser's basic hypothesis of two stages in perception - a duplex filter, but not a passive filter. The first filter precedes auditory (echoic) memory and filters out sensory signals the O actively deems irrelevant. However, if sensory relevancy cannot be immediately determined (without some kind of symbolic processing) then the signal enters the auditory (echoic) memory. Consequently, some symbolic information can be retrieved from this memory. If the O can immediately assess the sensory signal as being irrelevant to his decision, the information never enters the auditory (echoic) memory and subsequently is never retrievable, nor does it cause any interference.

The question now arises: how does the auditory duplex filter work? A sensory filter usually refers to the process of selection of specific items from parallel streams of sensory signals impinging simultaneously upon it. I would like to consider the first filtering mechanism a series gate. Auditory information flows through the first filter in queues (series) where it is possible that certain segments of the queue are blocked until they disappear and then the gate reopens to admit subsequent information. If the O knows and can easily identify what are the relevant and irrelevant stimuli (low stimulus uncertainty) the gate can be opened and closed very quickly, to the point where no irrelevant information can enter into the auditory (echoic) memory. If, however, the O does not know or cannot identify the relevant from the irrelevant stimuli (high stimulus uncertainty) then the gate's closing is delayed until the stimulus uncertainty is reduced. Whatever sensory signals pass through the gate are entered into the auditory echoic memory where they are temporarily stored and briefly are capable of being retrieved.

This conceptualization has numerous advantages. An auditory filter (gate) can, in part, account for: (1) Broadbent's filter theory, (2) Treisman's attenuation theory, (3) Neisser's analysis-by-synthesis theory, and finally (4) Helson's adaptation level theory.

Broadbent's filter theory does work for low uncertainty sensory information. However, if the information is symbolic it must enter auditory (echoic) memory after which some type of processing occurs, e.g., analysis-by-synthesis. The critical point at this stage concerns the physical characteristics of the signal itself. As previously stated, if the sensory signal is nonsymbolic, low uncertainty information, the auditory gate can block this information from entering memory. If, however, the signal is symbolic and /or high uncertainty information, the gating either remains open or is delayed. There appears to be subsequent filtering after the signal's symbolic content has been obtained and its relevancy determined. Of course some of the irrelevant information is retrievable to a degree - consequently,Treisman's attenuation theory.

Both Broadbent's and Treisman's filter theories are concerned with the mechanism of the second filter; however, their theories are antagonistic to each other (blockage vs attenuation) since neither theory postulates two filters each functioning according to its own input signal properties and information processing characteristics. Neisser does predict two filters, but one is a passive, and one is an active filter.

Helson's adaptation level theory (ALT) is concerned with only the first gating mechanism. Both Helson's ALT and the hypothesised gate are processing nonsymbolic information. When the auditory information has low stimulus uncertainty (in other words, the O can easily determine stimulus relevancy) the gate quickly opens and closes on the queue of information. At this time Helson's ALT does not function. However, when the auditory information has high stimulus uncertainty (the O cannot easily determine stimulus relevancy) the gate does not open and close quickly and some irrelevant information enters the auditory (echoic) memory before its relevancy is established. This suggests that the greater the stimulus uncertainty the more meaningful is Helson's ALT.

The hypothetical sensory gate postulated here is not a new idea. Neisser certainly was able to predict two filtering mechanisms. More will be said about this in the next subsection. For the moment, I would like to further develop the concept of probabilistic functionalism to human sensory information processing. Response uncertainty can be conceived in a similar manner to stimulus uncertainty.

Stimulus uncertainty has been defined as the relevancy the O attaches to the stimulus cues. Only highly identifiable (capable of segmentation) and relevant cues are accepted with low uncertainty, all other information never enters the auditory (echoic) memory. Relevancy has been defined as that amount and/or kind of information the O believes he needs to reach a decision. Consequently, if the O is not sure as to the kind and strength of his decision (as determined by the unvertainty of his sequence task) the more sensory information he needs to acquire in order to be able to make various responses. In the laboratory we can not only closely specify the relevant stimulus cues but also circumscribe the responses. Depending upon the degree of stimulus-response specification the O must accept or reject sources of sensory information with varying degrees of relevancy to his task.

In summary, an attempt has been made to discuss the paper's experimental findings in relationship to other investigations and theories from the philosophical framework of probabilistic functionalism. - Probabilistic because "the organism lives in a probabilistic world, (therefore) a theory about the organism must also be probabilistic (Brunswik, 1955, p.195)." Functionalist because, "perception must take into account the role of perception in adaptation (Heider, 1930, p.385)." "This role is to establish a contact between the organism and its environment; to enable, as it were, the organism to see 'through' the sensory stimulation to the constant environment. The environment can be a world of objects or a world of meanings .... They are the ultimate sources of the sensory stimuli that reach us. Adaptation can never be successful without a prior contact with these causal centres. However, sensory stimulation is ambiguous, it gives only incomplete information about its source. The same stimulation can be caused by several objects. Hence, the task of the perceptual system is to integrate many cues, each of which is itself, to a certain extent, unreliable. The perceptual system is usually quite successful in accomplishing this task (Sjöberg, 1971, p.30)."

Conclusion

This paper shares many heuristic assumptions concerning human information processing system with Hunt (1971).

> The central component is a Long-Term Memory (LTM) in which information is stored permanently. A hierarchy of peripheral, temporary memories, or buffers surrounds LTM. Each of these buffers has associated with it a computing device, i.e., some neural circuitry capable of examining information in the buffer. Two types of buffers are postulated. Sensory buffers, at the outermost level, receive raw information from the environment and code this information in a fixed manner. They are little affected by learning except, perhaps, over long periods of time. The coded data are passed through a sequence of identical intermediate buffers. Each of the intermediate buffers recodes data, but this time the coding is under the control of programs and data stored in LTM. Examples of the coding at this level are the transitions from collections of lines to letters, from letters to letter groupings, and finally to

> the recognition of words and sentences. Such codings are obviously automatic in the adult. They are also obviously learned (Hunt, 1971, p.59). Also see Fig. 11.

In Hunt's terminology, the auditory (echoic) memory is a peripheral or temporary memory called a sensory buffer, see Fig. 12. The auditory memory receives raw information from the environment and codes this information in a fixed manner. "The sensory buffer makes our first contact with the environment .... It contains: (1) a transducing mechanism, (2) a memory register, and (3) a feature detection unit. The transducer accomplishes a coding, without interpretation, of the physical input from an analog to a digital signal, which is then stored in the sensory register (p.60-61)." Hunt never mentions an auditory filtering mechanism in front of the transducer. From the studies presented in this paper the auditory filter (gate) is critical. The gate is controlled by the O's strategy for making his decision. Let us assume as Hunt did "that our environment consists mainly of highly redundant information which, if responded to in detail would quickly swamp our minds, p.60." If the filter (gating) mechanism was predeterminately set to reject irrelevant information, then only the relevant information would enter the transducer. Consequently, the information input has been reduced to only that information that is needed to reach a decision. The effectiveness of the filter (gating) mechanism is

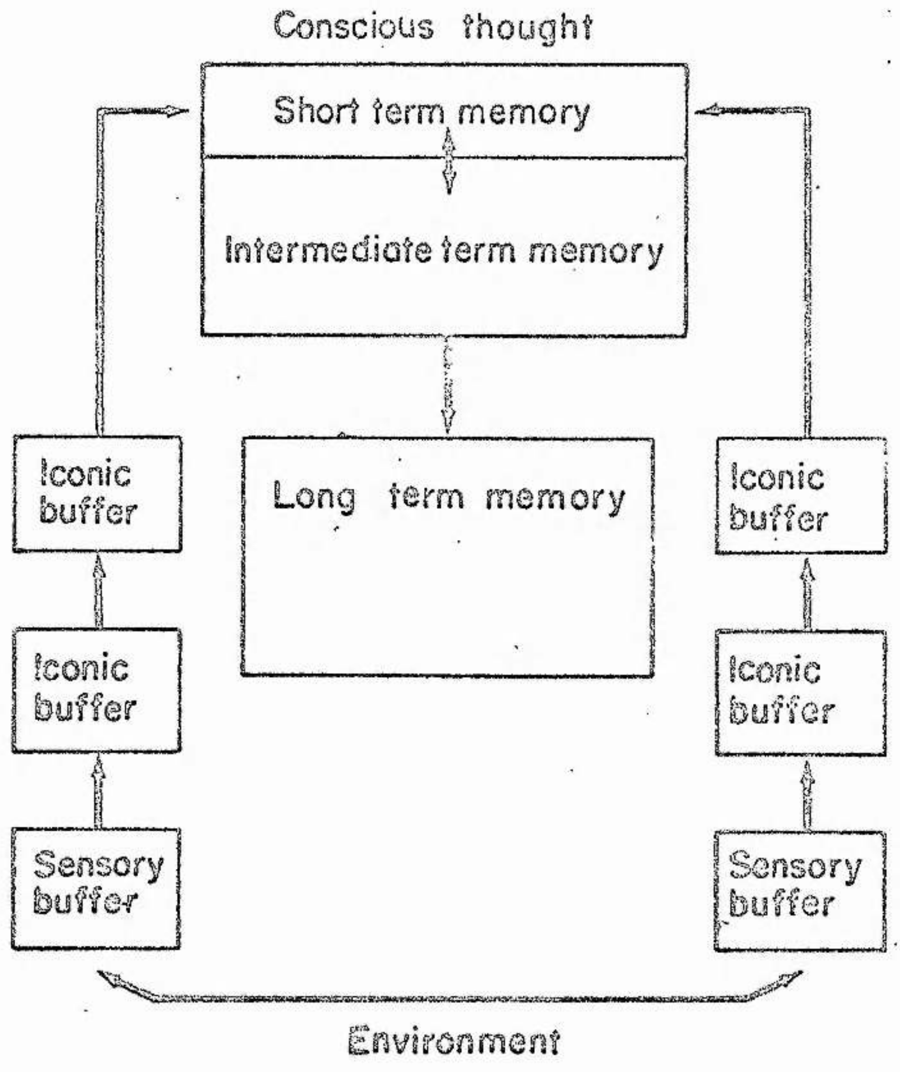


Fig. 11. Hunt's (1971) structures of simulated man.

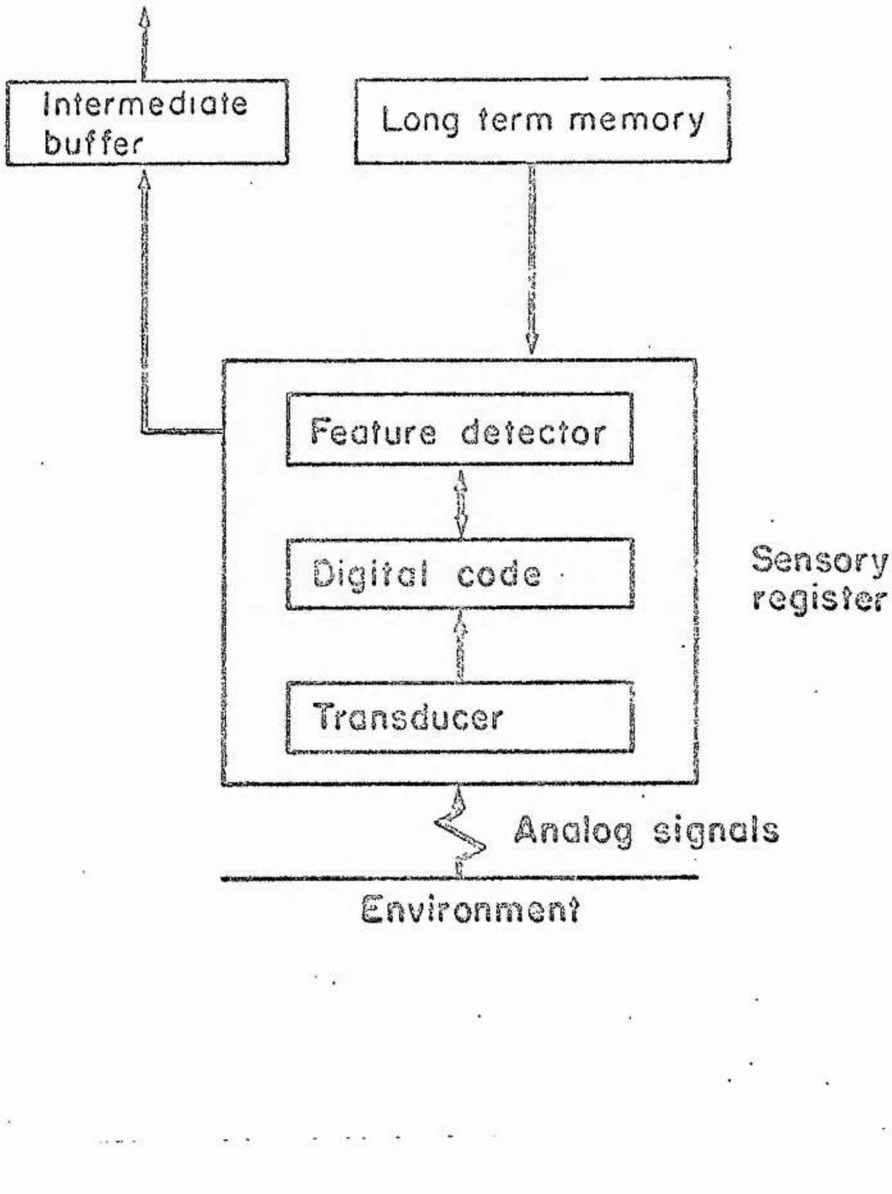


Fig. 12. Hunt's (1971) Structure of the sensory buffer.

determined by the O's certainty of sensory (nonsymbolic) information. The more certain the O is about the sensory information as to its relevancy to his decision (response), the more efficiently the irrelevant information is blocked and the relevant information passed to the transducer and to the memory register. Naturally, certainty is not binary, it is probabilistic. Consequently, the longer the O takes to establish the relevancy of the auditory stimuli the greater the chance of irrelevant stimuli entering the auditory (echoic) memory. Subsequent filtering mechanisms must now reduce the irrelevant stimuli, but once information has been allowed entrance to storage it can be retrieved.

Hunt's basic heuristic hypothesis is acceptable, but some refinements may be added concerning the auditory mechanism. The function of the "peripheral device is to screen important information from dross and provide the central computer with an orderly queue of data (Hunt, 1971, p.60)." The strategy of the screening device is that only relevant information enters into the buffer memory. The screening is accomplished at the auditory filter (gating) mechanism. Consequently, in Hunt's terms the peripheral auditory system consists of: (1) a filter (gating) mechanism, (2) a transducing mechanism, and (3) a memory register.

In conclusion, information processing organisation of the auditory system is probably a series of filtered storage mechanisms capable of progressive refinement in coding to distill out only the relevant information needed for a decision. The function of the peripheral auditory system is the first step in reducing the superfluous parts of the information input by establishing the relevancy of the sensory (nonsymbolic) information.

Chapter 8

Summary

Stevens (1959) used numerical ratio scales of subjective magnitude for three modalities (loudness, mechanical vibration on the finger tips, and electric shock to the fingers) to predict the form of the equal-sensation functions resulting from the pairs of sensations. Ten years later the present author performed an experiment to evaluate the relative accuracy of cross-modality matches of auditory magnitude and vocal judgments in the assessment of the same electrodermal stimulation. This study demonstrated the practicability of using one sensory modality to subjectively rate the stimulus magnitude in another modality. This study also found that Os had the most difficulty in gathering and processing those sensory data that were not verbally coded. Also, once sensory information is coded in speech patterns, it seems to influence other sensory judgments, thereby increasing the accuracy of the auditory matchings that accompany the vocal ratings. This effect could be attributed to either or both of two possible failures in the course of human information processing. First, if the Os do not perceive the sensory data accurately, they may assign less diagnostic value to the data than they in fact should. Or secondly, Os may be unable to integrate sensory information properly even though they may perceive the diagnostic value of any specific data correctly.

Experiment one demonstrated that the Os were having difficulty diagnosing the sensory information since an anchor point significantly improved performance. The assumption being that an anchor point will only aid in the assessment of the incoming auditory information and does not affect arranging, combining and organizing the incoming information; whereas, the conceptual rating scale (VCR) is capable of integration, and has a significant effect.

The same experiment also demonstrated that practice, experimenter, and residual effects do not significantly affect the O's performance.

The second experiment revealed that the anchor point serves as a pseudomemory for the O's cutoff point. Without the pseudomemory (anchor point) the O's cutoff point shifts throughout the session, thereby causing errors to be made for the CMM. The O's memory for his auditory cutoff point has a half-life of less than a second. The half-life of less than a second corresponds to other experiments which have attempted to determine the duration of the auditory (echoic) memory. When a VCR accompanies the CMM, the half-life of auditory memory increases to about three seconds. The half-life of the VCR is about four seconds.

The third experiment disclosed that the auditory memory is not prone to interference from signals of a similar nature. It was postulated that any auditory message that the O deems irrelevant is effectively filtered (gated) from entering the auditory memory.

Three separate findings: (1) the presence of auditory anchor improved the accompanying VCRs, (2) a decay in the auditory memory also resulted in a decrease in the VCR performance, and (3) a positive correlation between CMM and the VCR, lead to the conclusion that the auditory information was processed first and the VCRs based upon its resultant.

In conclusion, nonsymbolic auditory information is processed by a filtered, single channel, series processor. Persistency is added to the system's memory component by an interaction between the auditory (echoic) memory and a conceptual symbolic system (VCR).

Appendix I

Effects of Electrodermal Stimulation

This paper, by the author and Kheder, N., appeared in the Michigan Mental Health Research Bulletin in 1968, Vol. 2, pages 23-25.

Introduction

This study was conducted to determine the parameters of electrodermal stimulation as to: (1) psychophysical parameters of the stimulus, (2) physiological changes induced by the stimulation, and (3) O's autonomic response to the stimuli.

Method

Os (N = 8) responded to minimal intensity electrodermal stimulation presented by the method of limits. The stimuli varied in: (1) pulse repetition frequencies (PRF) as follows: 50, 75, 100, 200, 500, 700, 900, 1000, 1500, 2000, 2500, 2700, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10,000; and (2) duty cycle: 5%, 50%, or 95%. Each O was tested on all frequencies for each of the three duty cycles.

The frequencies per duty cycle were presented in three orders: ascending, descending, and randomly. The frequency, duty cycle and order of presentation were unknown to Os. The stimulus generator was a Tektronix 160 series. During stimulation a Darrow type bridge was used in monitoring Os' skin resistance; skin vasoconstriction and dilation, heart rate, and finger temperature were also constantly recorded.

Results

1. Os mean response levels for the different duty cycles over the same frequency ranges were significantly different (level of significance was beyond .05 as determined by multiple t-tests).
2. Os' resistance increased after being stimulated with frequencies ranging from 50 to 2000 (PRF) at the 5% duty cycle. The 50% and 95% duty cycles were followed by a decrease in skin resistance.
3. After electrodermal stimulation, there was a significant 10% increase in vasodilation and a 12% increase in heart rate without differentation as to frequency of the pulse train or its duty cycle.
4. There were no significant changes in finger temperature.

Discussion

The conduction mechanism of the skin could be compared to current strength and duration curve of a single neuron. The 95% duty cycle with its long "on-time" may be causing a considerable amount of neuronal accommodation. Therefore, more current is needed to stimulate hyperpolarized neurons. As the frequency increases, there is less and less real "off-time" and more current is needed to produce stimulation. This would be equally true for the 50% duty cycle but to a lesser extent than the 95% duty cycle.

The 5% duty cycle appears not to produce this effect because of its constant level of intensity (ma) across the frequencies 50 to 6000 PRF (above 6000 PRF Os did not indicate the presence of the stimulus even when the stimulus generator was at maximum output). In fact, the 5% duty cycle might be causing some depolarization, consequently more excitability of the neurons. The long "off-time" would dissipate any accommodation effects.

With higher frequencies, beyond 6000 PRF, another effect is occurring. The current has to flow for a certain definite period of time in order to be effective. If the current is turned on and off rapidly, it lasts such a short time that it will not stimulate, no matter how strong. Therefore, the finite period of current "on-time" for the skin must be in excess of 8.333 micro-seconds.

Appendix II

Cross-Modality Matching In Decision Making

This paper, by the author, appeared in The Journal of Auditory Research, 1969, Vol. 3, pages 200-206.

Introduction

S.S. Stevens (1959) established the validity of cross-modality matching by comparing auditory, vibrotactile, and electrotactile stimulation. An extension of Steven's work involves the question not only whether Os can make cross-modality judgments, but also whether sensory judgments are as accurate as verbal confidence ratings of the same stimuli. This study determined whether Os can detect the presence of a sensory stimulus with greater accuracy by responding verbally or by cross-modality matching.

Another aspect of this study was devoted to the increasing concern over some of the postulates of the Weber-Fechner tradition (Swets, 1961; Corso, 1962). The absolute threshold for a stimulus is often defined as that intensity which arouses a response 50% of the time. Confusion occurs when "detection" is interpreted as an intensity above "threshold" only, while "no detection" occurs below this intensity. There seems to be little *a priori* basis for adhering to this arbitrary definition. Empirically, a threshold may be defined as some point in the stimulus-response continuum which ranges from somewhere above "no detection" to 100% "detection". Such a continuum can simply be referred to as a sensory probabilistic zone. This study investigated the psychophysical parameters of the threshold region using two simultaneous stimuli, electrodermal shock and white noise, both at intensities within the sensory probabilistic zone. Each O was asked to: (a) adjust the loudness of Gaussian noise to the perceived intensity of an electrodermal stimulus, and (b) to give a vocal confidence rating as to the perceived magnitude of the electrodermal stimulus. Signal-detection theory techniques (Tanner, et al, 1956) were applied.

Method

Subjects. Four male and two female adults were tested, none with a history of otologic or neurologic disease.

Apparatus. Each O was seated in a double-walled audiometric test chamber. Ambient noise was below minimum U.S.A. Standards Institute specifications for audiometric testing. For the electrodermal stimulation, two electrodes were attached to the left hand. The positive electrode, made of conductive vinyl, 1.2 cm in diameter, was attached to the middle phalanx of the index finger. A similar electrode, attached to the middle finger, was used as ground. A Tektronix stimulator generating the 3000/sec pulse repetition frequency at a 35% duty cycle was used as the electrodermal stimulation. The standard (later used as the independent variable) electrodermal intensity (in milliamps) was determined by the method of limits using ascending, descending and random procedures and was established at the 50% response level for each O.

Gaussian noise was produced from a tape recording, routed into the calibrated input of a Beltone Model D audiometer and presented to each O through dichotic earphones. The attenuator of the audiometer was connected to a gear reduction device and used by Os to control sound level, with visual clues removed. A VTVM across the earphones indicated sound level.

Procedure. During the training session, O was instructed to match the loudness of the noise to a varying electrodermal stimulus. Repeated testing produced a stable loudness continuum of noise for corresponding changes in electrodermal intensity: at high levels of electrodermal stimulation, subject selected louder noises while for lower stimuli, he chose weaker noises. Consequently, an equivalence scale could be and was established between various levels of shock and sound. When the experiment began, the shock level was held constant at the O's 50% response level, O had no knowledge that the shock was now held at constant intensity. Hence, the noise level selected by the O could be used to determine his level of confidence or certainty as to the presence or absence of shock.

The shock was presented in a predetermined random order with catch trials 50% of the time, the pattern not known to O. He was simply told to (1) adjust the loudness of the noise to be equivalent to the perceived magnitude of the shock, and (2) vocally rate how confident he was that a shock was or was not present.

When a white light was on, O adjusted the loudness of the noise; when the white light went out, a red light turned on and O gave his vocal confidence rating as to the presence of shock. Verbal ratings were required along a continuum from 0-100%, where 0.49 represented decreasing confidence that the shock was absent, and 51-100 increasing confidence that the shock was present.

After data for the first 2 Os were completed, the possibility appeared of an interaction between the vocal responses and the auditory magnitude adjustments. In order to assess this possibility, for the next 4 Os, the trials were doubled: for the first 120 trials, only auditory magnitude adjustments were obtained (during this time, Os had no knowledge of the vocal rating scale), and for the next 120 trials both vocal confidence and auditory magnitude adjustments were obtained. The last 4 Os thus performed three types of confidence rating: (1) loudness adjustments during the first 120 trials in the absence of any other response mode, (2) loudness adjustments during the second 120 trials accompanied by vocal responses, and (3) the vocal confidence rating. Each response reflected the O's subjective confidence as to the presence or absence of shock.

Results

A "Receiver-Operating-Characteristic" (ROC) curve was established for the three different response modes: (1) auditory matching alone, (2) auditory matching accompanied by vocal responses and, (3) vocal confidence ratings. Unfortunately, the slopes of the ROC curves did not equal one; therefore, the area under the curve was calculated, Table 21.

Table 21

Area Under ROC Curve in Cm^2

Observers	Auditory Alone	Vocal	Auditory With Vocal
B.S.	N.A.	160.766	147.769
B.T.	N.A.	159.960	145.960
R.C.	120.480	123.001	115.173
J.S.	127.740	160.860	144.220
J.A.	148.740	158.030	152.670
B.R.	133.55	161.250	159.186

Since the area under each curve is larger than the area under the negative diagonal, each O was able to differentiate the presence and absence of shock better than by guessing. verification of a systematic response mechanism was obtained by a Chi Square analysis for all three response categories, which were significantly different ($p < 0.001$), indicating that the Os' detection accuracy was considerably better than chance (50%) detection.

The area under the curve was used as a comparison for the different responses by a Friedman Two-Way Analysis of Variance. The greater the area under the curve the more sensitive is O in separating signal from noise. The Friedman Two-Way Analysis of Variance is significant at the 0.042 level of probability.

For all Os, the verbal responses were more sensitive in detecting the presence or absence of shock than the auditory matchings. Also, 3 out of 4 Os had a larger area under the ROC curve for the auditory matching accompanied by vocal responses, than for the isolated auditory judgments. Therefore, Os were more accurate in detecting shock when the auditory matching was accompanied by the verbal responses than when not.

Discussion

Os had the most difficulty in gathering and processing those sensory data that were not verbally coded. Apparently, verbally coded material is more easily stored in memory and can be processed more accurately than sensory data. Once sensory information is coded in speech patterns, it seems to influence other sensory judgments, thereby increasing the accuracy of the auditory matchings that accompany the vocal ratings. This effect can be attributed to either or both of two possible failures in the course of human information processing. First, if Os do not perceive the sensory data accurately, they may assign less diagnostic value to data than they in fact should. Or secondly, Os may be unable to integrate sensory information properly even though they may perceive the diagnostic value of any specific data correctly. Therefore, since speech-coded data appears to be less affected by failures in information processing, as determined by the area under the ROC curve, information that is verbally coded can influence accompanying sensory data, thereby increasing its detection accuracy.

These results also demonstrate that Os are extremely effective in manipulating the Gaussian noise throughout their sensory probabilistic zone. These results are contrary to the classical notion of threshold as a point, not exactly constant but nearly so, above which sensory differences vanish in the "unconscious". This experiment clearly demonstrates that Os are capable of perceiving and manipulating signals throughout their sensory probabilistic zone and respond affirmatively only when the signal strength exceeds some subjective criteria.

These findings again emphasise the arbitrariness of the traditional concept of "threshold" inasmuch as there appears to be no break at the 50% response level in the O's response continuum. Since this response level appears to be arbitrary, one may question the usefulness of a binary or dichotomous "threshold" concept. There appears to be little or no conceptual advantage to the conventional concept of "threshold", since this study adds support to a stimulus-response continuum. The "threshold" concept appears to be a convention which has no biological nor heuristic significance.

Summary

Cross-modularity matching was performed using electrodermal stimuli in the sensory probabilistic zone ("threshold") and a simultaneously weak adjustable white noise signal. Os were able to adjust the loudness of the noise to the perceived magnitude of the shock, but verbal confidence ratings were more accurate in signal detection than auditory cross-modularity matching. Moreover, the verbal confidence ratings appeared to influence the accompanying auditory matching task by increasing the accuracy

of the latter. Once sensory data is verbally coded it appears to interact with the cross-modality matching task. Such an interaction effect could conceivably be attributed to one or both of two difficulties in human sensory information processing: (1) Os incorrectly perceive or understand the diagnostic value of the sensory information, and/or (2) Os had difficulty integrating the correctly perceived sensory information. Consequently, once sensory information is verbally coded it provides either an increased diagnostic value of the sensory data or increases the integration of the sensory data.

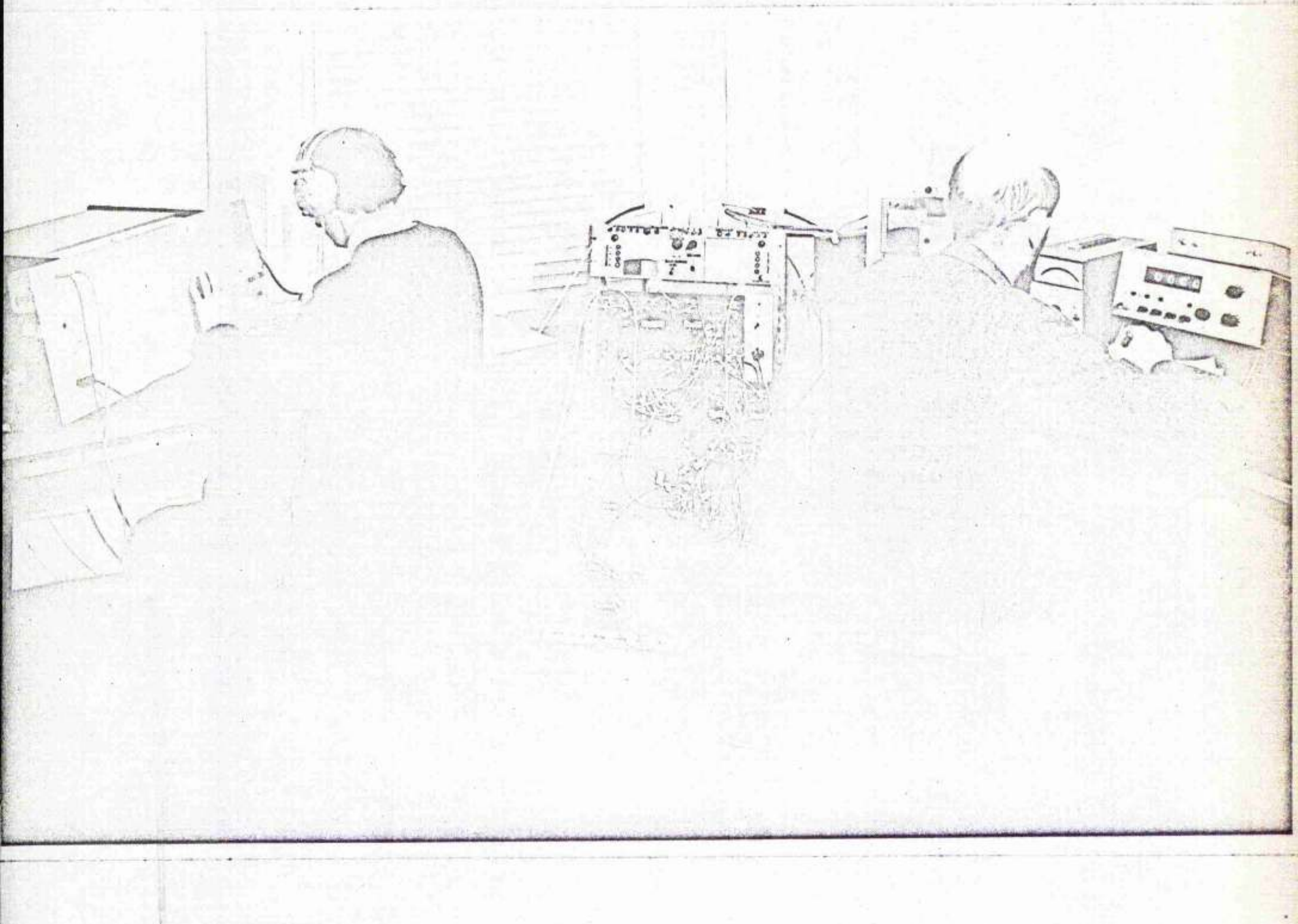
Appendix III

Instrumentation

All three experiments used the same equipment. The only piece of equipment that was altered was the AIM biosciences modular programming equipment.

Each O was seated in a quiet room facing a Peters AP.6. clinic audiometer, Photograph 1. The front panel of the audiometer was covered by a hardboard panel. On the panel was mounted the lights, starting switch and a gear reduction device that controlled the audiometer's 100 db attenuator.

A two wire shielded cable was attached to the audiometer's Gaussian noise (GN) generator and was then routed to an AIM bioscience relay, Fig. 13. (For experiments two and three different modules were used.) The relay (1) was closed by a timer (1) module that was started by the O pressing a switch mounted on the right side of the hardboard panel. When the timer completed its cycle not only did it open the relay (1), but it also started a second timer (2) that closed another relay (2). The second relay shunted the GN through a second attenuator located next to the relay module. This attenuator was controlled by the experimenter and set to each O's anchor point (reference point) before the experiment began.



Photograph 1.

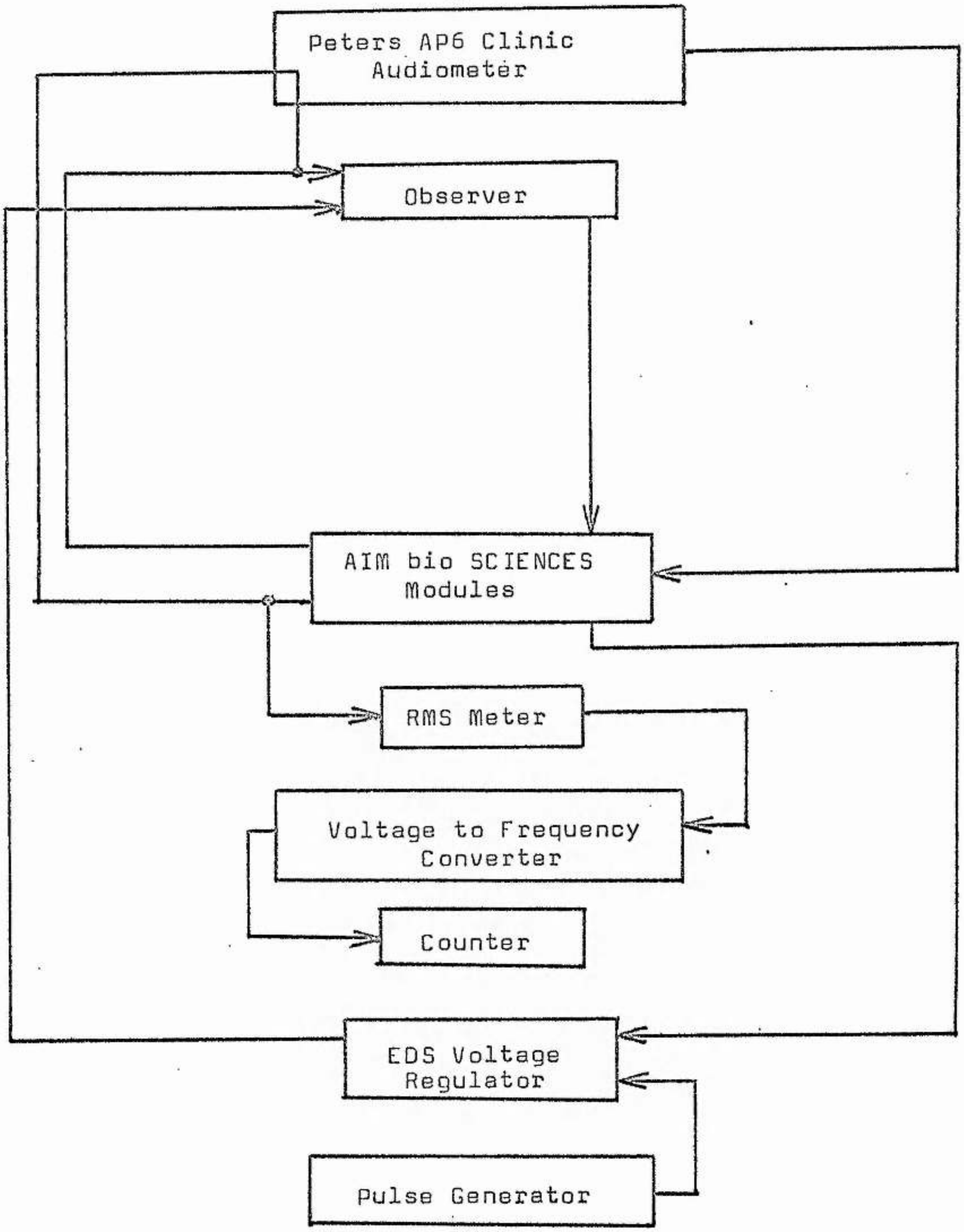


Fig. 13. Instrumentation.

The unattenuated GN from the audiometer was routed to two relays. When the first relay was closed, the GN loudness could be attenuated by the O's manipulation of the Peters' attenuator in front of him. The sound level O was hearing was under his control. A Hewlett Packard, RMS Voltmeter, 3400 A was connected across the O's earphones and measured root mean square voltage, the dependent data. The second relay routed the unattenuated GN through a second attenuator, controlled by the experimenter, and then was independently routed directly to the O's earphones.

The sequence of events performed by the AIM modules, once the O started the trial, was seven seconds of variable GN (the O could control the loudness of the noise), followed by seven seconds of the auditory anchor, and finally seven more seconds of the variable GN. During experimental conditions when an auditory anchor was not presented to the O, the second AIM's timer was uncoupled and the time duration extended on the first timer.

Even though the experimenter could read the O's loudness adjustment directly from the RMS Voltmeter this was not done. The meter readings were entirely automated. The back panel of the RMS voltmeter has a DC voltage output and is proportional to the meter displacement. The DC voltage was routed into a voltage to frequency converter. Consequently, a frequency of pulses (pulse train) was produced that was proportional to the meter displacement.

The pulse train was then routed into an Advance Counter. The reset operation on the counter was activated by the AIM's modules 0.250 milliseconds before the end of the trial. The counter displayed a number at the end of each trial that corresponded to the RMS meter displacement. Therefore, the Os' loudness adjustments were always sampled in the same time interval, and the experimenter could not overtly nor covertly read the wrong number from the meter.

For the electrodermal stimulation the O's left index and middle fingers, middle phalanx, were vigorously rubbed with Cambridge electrode jelly in order to reduce and maintain the O's skin resistance at the lowest possible level. Then the O placed his hand on a sponge where the two electrodes were mounted. The electrodes were normally quiescent until the O pressed the switch that started the trial. Then a pulse train of 3000 Hz at a five per cent duty cycle slowly appeared until the asymptotic curve reached a predetermined level. The ascending voltage curve has a duration of about 2.5 seconds from onset to maximum voltage. The reason for the slow ascending voltage of the pulse train is that human cutaneous sense is extremely sensitive to transitions. Consequently, even on catch trials the electrodermal stimulus was turned on for 1.5 seconds. Thereby the Os always had a transition at the beginning of each trial. The decay rate for the electrodermal pulse train was also a slow negative exponential function. The EDS started to decay at the end of the trial.

The EDS voltage regulator was activated by the O, via a relay (3) and terminated by an AIM's timer (3), and imposed 90 volts or less across the 100K variable resistor, which controlled the output voltage, and the transistors, Fig. 14. The resistor-capacitor (RC) network of 4.7K and 200μf exponential applied a voltage to the base of transistor 2N698. When the voltage was terminated by the timer (3), via the relay (3), there was a corresponding exponential decay as the capacitor slowly discharged across the resistor. When the base voltage slowly increased, the collector began to conduct voltage to its emitter which in turn was connected to the base of transistor 40411. The emitter of transistor 40411 was connected to the positive electrode via a fuse. The emitter output of the 40411 had a low output impedance in comparison to the O; therefore, voltage was regulated while current compensated for any small changes in the O's skin resistance. A voltmeter was connected between the emitter of the 40411 and ground. The voltmeter was used by the experimenter to keep the O's EDS at the same voltage for all his sessions by adjusting the 100K variable resistor. The 10K resistor to the base of transistor 2N4409 via the diode was connected to a pulse generator. The pulse generator

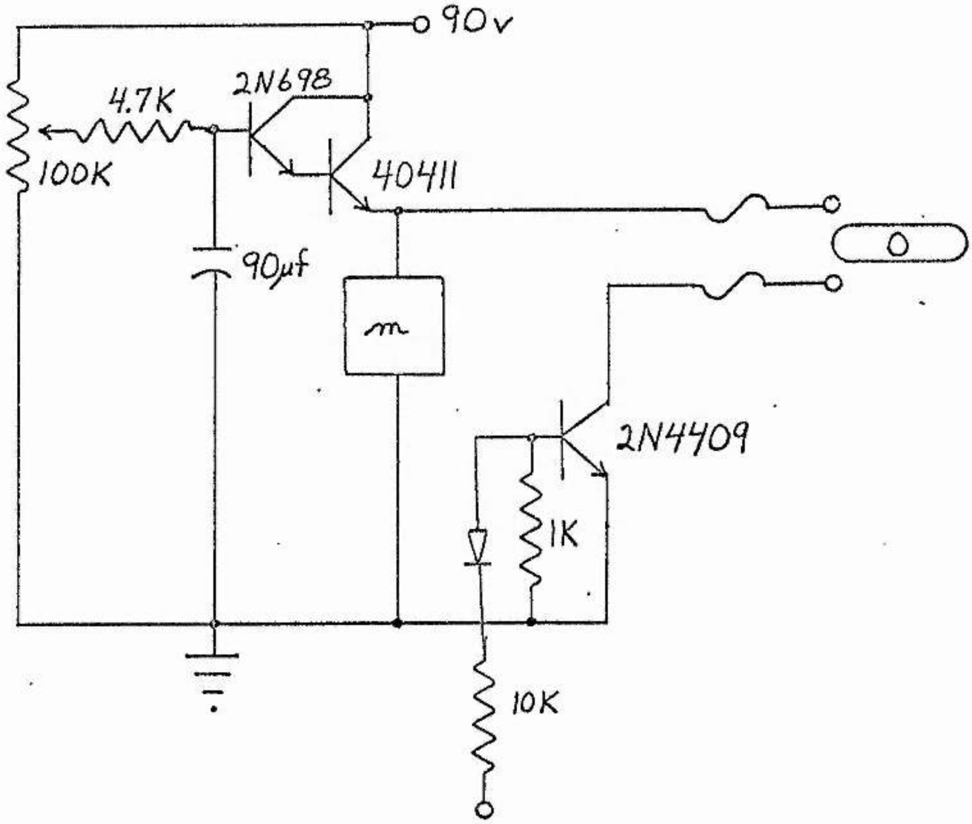


Fig. 14. EDS circuit.

had a set output of 3000 Hz at a five per cent duty cycle. Consequently, the impressed voltage across the O was connected to ground, via a fuse, only when there was a pulse applied to the base of transistor 2N4409.

A dichotomous tape reader determined whether an EDS would be presented or whether it was a catch trial. The tape was programmed to randomly present either EDS or catch trials. The same tape was used for all Os in the three experiments. Consequently, neither the O nor the experimenter knew in advance whether the next trial was going to present a stimulus or if it was a catch trial. This information was conveyed to the experimenter during the trial by a light on his control panel.

For experiments two and three, the AIM's timers were used to step a shift register. In experiment two, the shift register's schedule was: (1) seven seconds of variable GN, (2) a delay period set by the experimenter before the session began, (3) auditory anchor, (4) the second delay period of the same duration as the first delay period, and finally (5) seven more seconds of variable GN.

In experiment three, the same schedule as experiment two remained on the step register. Except, now, the former delay period was maintained at a duration of one second and the period contained one of four interfering signals. The interfering signal was GN from the

Peters' audiometer. Its amplitude (loudness) was controlled by a third attenuator in front of the experimenter. The experimenter randomly altered the loudness of the interfering signal after each trial.

Glossary

This glossary contains the most important technical terms used in this paper except for terms used essentially in their usual dictionary meaning which are omitted. The definition to some of the terms pertain only to this paper.

Anchor point. An O makes a series of comparisons of how far a sample deviates from a reference. The reference is considered to be an anchor in that all other samples are compared to it. In this study the O's anchor is the loudness of the Gaussian noise set at an amplitude that would arouse a response 50 per cent of the time.

Assimilation effects. Assimilation occurs when the effect of the anchor is to move the sensory judgments of the control stimuli (sample) <u>toward</u> the portion of the scales used in judging the anchor.

Auditory fatigue or adaptation. Whenever a pure tone (a specific frequency) is presented to an O there will be a temporary hearing loss depending upon the length of the tone's persistence.

Auto Kinetic. A form of apparent motion in which a dim light in a completely darkened room appears to move.

Cognition. The flow of information in the organism.

Conceptual. Concepts are the mental classification or ordering of general notions.

Contextual effects. Presentation of an anchor produces a shift in the O's judgment of the stimuli toward that portion of the judgment scale most distant from that used for judging the anchor.

Cross-modality facilitation. Performance in one modality is improved by the presentation of a signal to another sensory modality.

Cross-modality matching (CMM). The degree of accuracy with which a stimuli in one modality can be matched across to another modality. For example, an O must subjectively match the brightness of a light to the loudness of a tone.

Cybernetics. The word cybernetics is derived from Greek and means steersman. It is concerned with the communication and manipulation of information and its use in controlling the behaviour of biological, physical and chemical systems and includes the entire field of control and communication theory. There are four basic kinds of cybernetic problems. The direct problem is when the input, laws and properties are known and the problem is to determine the output. For example, a cryptologist has a coded message to decipher. He knows the message was sent by Morse code (input). He also knows its language, e.g., Russian. The cryptologist also speaks Russian and consequently knows the laws that govern its grammatical use. His task is to decode the message (output).

The converse problem is when the law, properties and output are known and the problem is then to determine the input. For example, a child has taken poison. The physician knows the laws and properties of a normally functioning body. He then measures the output from the child's body, e.g. temperature and white blood cell count, and determines how and where the child's body deviates from normal. From this information the physician can hopefully determine what kind of poison went into the child's system.

The inverse problem is when the input, laws and output are known and the problem is then to determine the properties of the system. For example, an engineer knows the input to an engine (petrol) he also knows the engine's output, e.g., torque, temperature and unburnt petrol in the exhaust. The engineer is also familiar with physical laws like the second law of thermodynamics. The engineer's task is to determine the properties of the engine, e.g., capacity, bore or compression.

The <u>inductive</u> problem is when the input and the output are known and the problem is to determine the laws and properties of the system. The same hypothetical example can be used as in the engineer's problem. Except now the engineer does not know the physical laws, e.g., second law of thermodynamics. Not only does the engineer have to determine the properties of the engine he also has to discover what laws govern these properties.

Diagnostic. A decision derived from the examination of information. It is synonymous with analytical, distinctive and symptomatic. Simply it is the process whereby the O assigns relative value or weight to the auditory signals.

Duty cycle. In any one period, onset of one rising waveform to the onset of the next rising waveform, it is the percentage of time the waveform is on in relation to the amount of off-time.

Echoic memory. It is the preliminary and transient storage mechanisms for auditory information.

Empirical. Empirical has to do with experience but the word has at least two meanings which are commonly confused. Erlebnis refers to present experience that which is immediately there without reference to its origin. Whereas Erfahrung is the accumulation of past Erlebnisse.

Equivalence. It is the process whereby information gathered by one perceptual system is covariant or correlated with the information obtained by another perceptual system. It is the subjective equalisation in force, amount or value of sensation impinging upon two different sensory modalities.

Facilitation. It is the increased ease of detecting the presence or magnitude of sensory stimuli in one modality by introducing a sensory stimuli to another modality.

Gaussian noise (GN). Noise as opposed to a tone, does not have a clear pitch. In a musical tone all the partials are multiples of the fundamental frequency. In noise there is no such relationship of the component frequencies. The frequencies have an aperiodic relationship to each other and the spectrum is uniform in amplitude and random in phase. Gaussian noise contains components of all audible frequencies sounding simultaneously.

Half-life. The time necessary for half the magnitude of any sample to decay or disintegrate.

Information processing. The flow of information within the organism.

Integration. It is the process whereby parts are added or brought together. Synonymous with amalgamation, arrangement, combination, consolidation, fusion and organization. Simply integration is the process of combining, organizing or co-ordinating the diagnosed auditory information. Conceivably there are two basic types of integration; the first is the fusion of different categories of information, the second is the consolidation of one kind of information that changes with time. The latter type of integration is of concern in this paper.

Intervening variable. It is a construct used as a logical connection between those conditions that establish it and the effect of these conditions on behaviour.

Masking. The elevation of the threshold for one tone by a second tone sounding simultaneously.

Method of limits. It is the direct method for threshold determination. The O has been instructed to report "yes" when he hears a tone and "no" when he hears nothing. The stimuli are presented in increasing and decreasing orders of intensity, trial by trial. Some trials begin below absolute threshold, others begin above.

Perceive. It is the process of comprehension, recognization or observation. Means to become aware of stimuli through the senses.

Pooling effect. Intrinsic stimuli interact with the external stimuli to produce a pooled effect which establishes a given level of activity in a particular behavioural setting, Helson's Adaptation Level Theory (ALT).

Proactive interference. Stimulus one is presented prior to stimulus two that is now being tested. Stimulus one interferes with the processing of stimulus two.

Probabilistic functionalism. The organism's perceptions are never completely valid representations of the physical world of objects, sizes, shapes, colours. Consequently the organism establishes "hypotheses" a probabilistic about the external world.

Relevant. The amount and/or kind of information the O believes he needs to reach a decision, Or the kind of response the O believes he needs to make.

Retroactive interference. Stimulus one is presented prior to stimulus two. When stimulus one is tested, stimulus two has interfered with its processing.

Root-Mean Square. When referring to an alternating current value, the value that corresponds to the direct-current value that will produce the same heating effect.

Semantic. Relates to the significance or meaning of an item or items.

Sensory transfer. Occurs when an organism uses information from one sense modal to perform a task or solve a problem on a different sense modal.

Steven's power function. Psychological sensation in human perception is related to physical stimuli as an exponential function, as opposed to Fechner's logarithmic function

Syntax. It is the orderly or systematic arrangement of parts or elements.

Threshold. A point on a stimulus continuum which produces a response 50 per cent of the time.

Uncertainty. Stimulus. The relevancy the O attaches to the stimulus cues. Response. The O is not sure of the kind or degree of response(s) required of him.

von Restoff effect. The O "learns" the odd item in a sequence of like items.

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